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SPRAY ACCOUNTANCY REVIEW - A LITERATURE SEARCH

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Douglas G. Boyle is a retired employee of the U.S. Army Dugway Proving Ground (DPG), Utah where he was deputy director of Materiel Test Directorate, the senior civilian position in Dugway's field test organization. Other major assignments include Chief, Test and Instrumentation Division, Armament Research and Development Command, Dover, New Jersey; Chief, Experimental Systems Division, Project Deseret, Ft. Douglas, Utah; and Chief, Chemical Test Design and Analysis Division, DPG. For a five-year period, Mr. Boyle headed the Statistical Design and Analysis group plant of Hercules, Inc., Utah.

Mr. Boyle's involvement with aircraft spray application dates from 1953, when he was assigned a project involving counting and sizing droplets of volatile sprays. The assignment included review of aircraft spray tests conducted by the Allies during World War II, work summarized by the U.S. National Defense Research Council and the Project Coordination Staff, sponsored jointly by the United States, United Kingdom, and Canada. In many cases, Mr. Boyle was able to locate original biographic sources and ensure their preservation, becoming recognized within the U.S. military as an expert in the early history of aircraft spray. He has remained close to the field throughout his career and has been a panel member and participant in numerous national and international aircraft spray symposia. In recent years he has been a volunteer with the USDA Forest Service providing technical assistance to Program WIND.

FPM 89-3
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Spray Accountancy Review - A Literature Search

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PREFACE

The USDA Forest Service (FS) has identified a need to intensify its continuing research program concerning the fate of pesticides released into the atmosphere. Current field sampling techniques used by the FS to monitor the fate of aerially-released pesticides frequently account for less than 30 percent of the emitted pesticide and its carrier. Concerned about the potential for human and environmental risk, the FS is embarking on a course that will lead to an improved understanding of the processes and application of technology for environmental accountancy of aerially-released pesticides. The initial process includes literature searches to determine how others have studied and sampled the fate of biologicals/chemicals released into the atmosphere, use of computer-based predictive models, and conduct of controlled field experiments. The FS encourages cooperation with other Federal and State agencies in pursuit of this need. Funding for this study was provided by the FS Northeastern Area State and Private Forestry, Appalachian Gypsy Moth IPM Demonstration Project, Morgantown, WV and Washington Office, Forest Pest Management Staff.

The FS expresses its appreciation to Dr. Lothar Salomon, Dr. Don Parker, Mr. Bruce Grim, and Mr. Ron Stricklet, DPG, for their cooperation in providing access to data and for typing support.

All summary reports, with the exception of the B 502 series, were prepared by the staff of U.S. Army Dugway Proving Ground (DPG), Chemical Test Design and Analysis Division and its successor organizations. The Division has been headed by Dr. Richard I. Jackson (1956-1964) and Mr. Boyle (1964-1975). The principle author of several referenced aircraft spray reports was the late William C. McIntyre, who for over 30 years was DPG's spray test expert.

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INTRODUCTION

1. APPROACH

The unclassified technical literature available in the technical library at the U.S. Army Dugway Proving Ground, Dugway, Utah, dealing with liquid sprays and aerosols in the 10 micron to 2,000 micron size range has been reviewed. A descriptive bibliography has been prepared. Also, when material of general or historical interest was found, an extract of the report itself was prepared.

2. CRITERIA

In selecting reports for review, the following three criteria were applied:

a. Droplet size greater that 10 microns. In effect, this criterion eliminated from consideration spray trials in which vapor clouds were disseminated as well as tests on which clouds of very small particulates were disseminated. There are two exceptions: (1) Reports of one major FP program, BW 502, have been included as an example of large-scale tests. (2) two trial records in which biological simulants were tested have been included. The latter reports are excellent examples of cloud symmetry measured on a vertical sampling tower they are included in the accountancy summary for that reason.

b. Sampling conducted and recovery estimates made. Trials on which light and variable winds precluded recovery calculations as well as trials on which only qualitative recovery estimates were made were reviewed but not extracted.

c. Military Weapons. Testing involving the evaluation of hardware to assess conformance with weapons system specifications were not reviewed.

3. DESCRIPTIVE BIBLIOGRAPHY

A descriptive bibliography of all reports reviewed has been prepared. When a report was judged relevant, an extract was prepared giving methods used as well as estimates of variabilities, uncertainties, and accuracy and precision estimates, if present in the report. Programs on which additional analysis appears warranted are identified.

4. The spray trials reviewed span a period of 31 years, with abbreviations, symbols and descriptive terminology constantly changing. For that reason a glossary of terms and symbols has been prepared. Much of the material there presented is based on the recollections of the preparer who alone is responsible for any errors inadvertently introduced.

TABLE 1. SPRAY ACCOUNTANCY SUMMARY

TEST SERIES	TRIAL	RECOVERY HZ (%)	RECOVERY VT	DROPLETS VMD (μ)	DROPLETS NMD	FLOW (kg)	FLOW (l/sec)	MATERIAL USED	METEOROLOGICAL HR (m)	WS (m/sec)	σ_A (deg)	σ_E (deg)	H_M (m)
1. DTC 70-11	1	78		191		406	57	BIS	70	8.7	1	1	140
	2	89		205		406	77	TOF	218	3.0	3	3	256
	3	96		162		405	73	BIS	104	9.8	1	1	175
	4	99		267		405	76	TOF	130	8.0	1	1	150
	5	95		237		616	125	BIS	110	8.0	2	2	355
	6	86		141		564	78	BIS	145	4.0	2	2	175
	7	92		158		858	80	BIS	129	4.5	2	2	204
2. DTC 70-11		This report prepared by H.E. Cramer Co. contains downwind drift data for report cited above as well as analysis of small droplet behavior.											
		(%)	(%)	(μ)	(μ)	(oz/a)	(l/min)		(m)	(m/sec)	(deg)	(deg)	(m)
3. C-980	2-2R	11	50	58	36	5	227	Fuel oil	50	4.0	5	5	350
	2-3	11	50	51	32	2	95	Fuel oil	50	4.2	5	3	500
	1-7	47	105	63	47	2	95	Duphar	40	1.8	10	10	400
	1-6	76	93	71	46	5	227	Duphar	46	1.0	5	5	150
	1-5	11	50	56	33	5	227	Fuel oil	52	3.1	10	10	850
		(%)		(μ)	(μ)	(gal/min)			HR (ft)	WS (m/sec)	ΔT (F°)		
4. DTC 73-317	1	89				150		Zectran	174	1.5	-2.5		
	2					150		Zectran	203	2.0	-2.1		
	3			120	110	150		Zectran	328	2.2	0.0		
	4					150		Zectran	150	1.0			
	5					150		Zectran	150	2.0			
	6					150		Zectran	140	3.5			

TABLE 1. SPRAY ACCOUNTANCY SUMMARY (Cont)

TEST SERIES	TRIAL	RECOVERY	DROPLETS	FLOW	MATERIAL USED	METEOROLOGICAL HR	WS	ΔT
		(%)	(μ)	(gal/sec)		(ft)	(m/sec)	(F°)
5. C 599	A-1	90	200	38.7	BIS	450	10.7	-4.2
	A-2	58	175		BIS	930	26.4	0.7
	A-3	61	200	53.8	BIS	980	3.7	0.9
	A-4	89	150	44.7	BIS	470	17.5	0.4
	B-1	56	250	39.4	BIS	1175	21.5	3.9
	B-2	69	250	30.8	BIS	720	19.7	0.6
		(%)	(μ)	(gal/sec)		(ft)	(mph)	(F°)
6. C 582	A-1	84		3.5	BIS	288	1.5	
	LA-2	79		3.3	BIS	315	5.5	
	A-3	70		2.9	BIS	225	3.1	3.0
	B-1	74		3.8	BIS	323	7.6	3.1
	B-2	61		3.3	BIS	320	3.1	1.3
	C-1	100		2.9	BIS	368	2.2	2.3
		(%)	(μ)	(gm/sec)		(ft)	(mph)	(F°)
7. C 607	1	66	250	77,000	BIS	1,380	17	5.8
	2	77	250	31,000	BIS	710	13	0.3
		(%)	(μ)	(gm/sec)		(ft)	(mph)	(F°)
8. C 442	A-1	76	275	33,666	BIS	165	10	-0.1
	A-2	79	275	38,333	BIS	195	19	3.0
	A-3	73	275	35,512	BIS	230	12	3.0
	B-1	75	200	35,357	BIS	300	11	-0.5
	B-2	66	200	36,144	BIS	240	14	10.2
	B-3	77	200	39,722	BIS	230	22	0.0
	B-4	79	200	40,441	BIS	65	16	0.0

TABLE 1. SPRAY ACCOUNTANCY SUMMARY (Cont)

TEST SERIES	TRIAL	RECOVERY HZ (%)	RECOVERY VT	DROPLETS VMD (u)	DROPLETS NMD	FLOW (gal/sec)	MATERIAL USED	HR (ft)	METEOROLOGICAL WS (mph)	METEOROLOGICAL ΔT (F°)
9. C 432	2	85		285		11.8	LNA/LNB	350	22.0	3.8
	3	103		260		11.6	(50-50 mix)	700	9.8	0.6
	4	101				7.0		270	14.9	0.3
	5	98		227		7.0		240	17.3	>10.0
	6	85		202		7.0	LNA/LNB	450	9.0	5.5
		(%)	(%)	(u)	(u)	(g/m)		(ft)	(mph)	(F°)
10. C 679	A1					8.2	Methylene		11.2	-3.2
	A2					9.4	Chloride		16.0	-3.6
	A3		250						16.6	-5.2
	AIR		74			22.7			4.4	-3.9
	A2R					19.9				-7.8
	A4					30.5				-2.2
	B1		124			40.3			12.0	-3.7
	B2					45.2			9.3	-3.0
	B3		12			38.5			6.4	

REFERENCE 1

Technical Report

C-Series

AD B058691*
ACC 534270

Date: 810300
Test Series: none

U.S. Marine Corps Chemical Logistics Evaluation. Supplemental Technical Report No. 2. H.E. Cramer Co. DPGTR T135 M. March 1981.

Dumbauld, R. K., and Bowman, C. R.

The problem addressed by this report is the determination of a logistically optimum spray system from among three competing systems. Deposition pattern and area coverage at desired deposition levels are the optimization criteria. The area coverage potential for the three systems is compared using a 1977 version of the Cramer model later developed as the FSCBG line source model.

No extract of this report has been included. It is worth noting that a diffusive deposition model can be used to optimize a logistics problem. There are two supplements to this report:

1. AD B058 054L/ACC 534 251 supplemental Technical Report for U.S. Marine Corps Logistics Evaluation - Deposition Patterns for the Tactical Use of Aero 14B Spray Tanks Mounted on A4 Aircraft. Rafferty, J. E., and Dumbauld, R. K., H.E. Cramer Co. February 1981.

2. AD B058 691/ACC 534 270 second Supplemental Technical Report for U.S. Marine Corps Chemical Logistics Evaluation - Comparison of the Aero 14/B, TMU 28/B and BLU 80/B Spray Delivery Systems. Dumbauld, R. K., and Bowman, C. R., H.E. Cramer Co. March 1981.

Neither supplement has been extracted.

*The AD number is the accession number of the document at the Defense Technical Information Center (DTIC). The ACC number is the accession number at the Dugway Proving Ground Technical Library.

REFERENCE 2

Final Report

C - Series

AD C 009 258
ACC 538 787

Date: 770200
Test Series: 70-11

Evaluation of Delivery and Assessment Techniques for Aircraft Spray (simulant) Systems. DTC Test 70-11, Phase I, Subtest 3. DPG-FR-T 115A-13. February 1977.

Taylor, Wilbert T., Eckard, Cecil O., et al.

Seven trials were conducted in the summer and fall of 1972 to demonstrate the suitability of a spray simulant approved for use on troop tests when disseminated using ram air tanks mounted on high performance jet aircraft. The material approved for troop tests is identified as TOF, an acronym for trioctyl phosphite. It was compared in a 2 X 2 test matrix with BIS, an abbreviation for bis(2-ethylhexyl) hydrogen phosphite. Both compounds were tagged. First, a red dye, du Pont oil red, was added, at a rate of 6g/l, to measure droplet stains. Second, two colors of fluorescent particles were added to allow sizing of small drops captured on rotorod samplers at downwind distances as great as 15 miles from the release line. Source strengths of 658, 870, 1678 and 1722 kg. were achieved. Release heights ranged between 70 and 145 meters at wind speeds between 4.0 and 9.8 m/s. Recoveries fell between 78 and 99%.

An extensive sampling array was used, with downwind lanes at 1/2 mile intervals through 3 miles and at 1 mile intervals through 15 miles. Also, sampling was done on a 90-meter tower arrayed with both rotorods and cylindrical samplers wrapped with filter papers.

An extract of this report has been prepared. (APPENDIX I) The extract includes:

Scope of Testing
Data Aquisition Procedures
Sampling Array
Recovery Estimates
Droplet Spectra Data

There is no discussion of accuracy and precision, per se. Also, in presentation of droplet data the report appears mis-assembled. A major aspect of the overall 70-11 test was the study of droplet drift. Droplet drift is addressed in an H.E. Cramer report, Comparison of Calculated and Observed Dosage and Deposition for Subtest 3, 70-11 Test Series. Nov 1976. AD B015 939L, ACC 532 194. (APPENDIX II)

REFERENCE 3

Technical Report	C- Series

AD B 015 939L
ACC 532 194

Date: 761100
Test Series: 70-11

Comparison of Calculated and Observed Dosage and Deposition for Subtest 3, 70-11 Test Series, TR 76-303-02, H.E. Cramer Co. November 1976.

Dumbauld, R. K., and Rafferty, J. E.

This contractor report addresses the second objective of the 70-11 Test Series, the development of sampling and assessment technology for droplets less that 100 micrometers in diameter. For this study droplets were tagged with fluorescent particles (FP) in a way that allowed an estimate of droplet volume from the number of FP's observed. Data on which this report is based are reported in Evaluation of Delivery and Assessment Techniques... DTC Test 70-11, Phase I subtest 3. AD C 009 258/ACC 538 787.

A copy of this report has been included (APPENDIX II) because of its relevance to the droplet drift problem. This project deserves further study. There does appear to be an erroneous use of "km" for "m" on two downwind travel illustrations. These errors have been corrected in the extract included in this report.

REFERENCE 4

C- Series

AD A 102 632 Date: 751100
ACC 530 776 Test Series: C- 980
DC-7B Aircraft Spray System for Large-Area Insect Control. DPG-DR-C98 A.

Boyle, Douglas G., Barry, John W., Eckard, Cecil O., et al.

Ten trials of an aerial spray system installed in a DC-7B four-engine aircraft were conducted in October 1974 for the Food and Agricultural Organization (F&AO) of the United Nations. The broad objective was to characterize a system capable of operating in remote areas with no on-site logistical support, a mode of operation compatible with the fuel capacity and range of the DC-7B. Two spray formulations, fuel oil and Duphar, were sprayed at each of three flow rates. Three types of trials were conducted:

a. Tower "fly-bys" designed to measure operating efficiency. On these, a three-hundred foot tower instrumented with inertial samplers (pipe cleaners and printflex-wrapped beer cans), together with a sparse horizontal array of printflex cards, was used.

b. "Swath width" trials flown into the wind. The sampling array used was a three-mile square of printflex cards supplemented by three lines of more dense sampling, laid out normal to the predicted wind direction.

c. "Drift" trials with sampling extending to 15 miles downwind. On these trials, fluorescent particles were added to the spray mixture to measure droplets too small to leave a visible dye stain on printflex cards. Rotorods were used to sample and measure FP- containing droplets. Of the ten trials conducted, five proved suitable for computer modelling. Results of the predicted vs. observed deposition pattern are presented in the report. The report also contains a summary of a technique for establishing droplet-stain relationships for droplets less than 40 microns in diameter.

An extract of this report has been prepared. (APPENDIX III) The extract includes:

Scope of Testing
Methods
Results
Droplet Spectra Data
Mathematical Modelling
Horizontal Recoveries
Vertical Recoveries
Predicted vs Observed Deposition Patterns

Although there is no discussion of accuracy and precision, per se, this report is comprehensive in nature and is an excellent example of how to conduct, evaluate, and report a major spray program. There are minor inconsistencies, mostly due to using test plan pages in the report without revision, a choice dictated by funding limitations.

The droplet data and meteorological data obtained on this trial should be made a part of the data base on spray cloud behavior. The project warrants further study.

REFERENCE 5

Final Report

C- Series

AD 906 189L
ACC 529 674

Date: 721200
Test Series: 72-317

Services Development Test PWU-5/A USAF Modular Internal Spray System. DTC-FR-73-317. December 1972.

Taylor, Wilbert T., McIntyre, W. C., Barry, J. W., et al.

Seven trials were conducted in the spring and summer of 1972 to determine the usefulness of an Air Force-developed spray system designed to be compatible with the C-130, C-54, C-47 and other transport aircraft, giving such aircraft a modular, reusable, high capacity aerial spray system capable of disseminating defoliants, herbicides, pesticides and fertilizers when disseminated as solutions, suspensions, or slurries. Six of the seven trials were run over an instrumented grid array at Dugway Proving Ground. The seventh test was run at Lolo National Forest, Montana. A carbamate insecticide was sprayed, dyed with du Pont oil red to facilitate droplet stain sizing. Although data are presented for all trials, a recovery calculation is presented for only one trial, trial FS-1, on which a recovery of 89% was observed.Mathematical modelling was used to calculate distances between flight paths.In addition to printflex card and filter paper samplers, spruce budworm larvae, 10 larvae per Petri dish, were used on one trial to correlate budworm mortality and deposition density.

Release heights ranged between 174 and 328 feet above ground; wind speeds between 1.0 and 3.5 m/sec.; stabilities fell between inversion and neutral. The mass mean diameter for the insecticide mixture was approximately 150 microns.

An extract of this report has been prepared. (APPENDIX IV) The extract contains essentially the entire report, omitting only some non-reproduceable photographs, table of contents, etc. The data underlying this report should be made a part of the data base on spray cloud behavior because of the insecticide spruce budworm larva mortality comparisons.

REFERENCE 6

R & D Task Summary Report

C-Series

AD 515 628
ACC 521796

Date: 710500
Test Series: none

Experimental Evaluation of Chemical Agent Simulants, R & D Task Summary Report, May 68-Dec 69. GCA Corp. Bedford, Mass.

Tull, David B.

This report contains a discussion of the physics of selecting inert liquids to be used in aircraft spray tests in lieu of more chemically active compounds impossible to test in some locations. The report includes discussion of the liquid breakup phase, the meteorological fallout phase, and contact hazard or transversal hazard phase. Physical properties of candidate simulants are rated as follows:

Density	40%
Surface tension	32%
Volatility	10%
Viscosity	10%
Diffusion Coefficient	4%
Hygroscopicity	4%

No extract has been included.

REFERENCE 7

Summary Report

B - Series

AD 865 794L
ACC 529 976

Date: 700200
Test Series: B 502

Downwind Diffusion from Aerial Line Source Release at Dugway Proving Ground.

Freeze, James E., and Hereim, A. T.

The B 502 test series began in 1960 and was completed in 1966. It consisted of 22 trails divided into two phases, A and B. The B 502 test series involved the use of particles less than 10 microns and thus, technically, falls outside the scope of this spray accountancy review. It has been included because of the scale of testing, the diversity of sampling techniques used, and the quality and extensiveness of the B 502 analysis by both government and civilian scientists.

Phase A consisted of six successful trials run in 1960 and addressed two questions: (1) Would fine aerosols, aerosols with a particle size generally less than 10 microns released at heights as great as 240 meters reach the ground in a predictable manner; and, (2) Could dry materials such as small fluorescent particles be dispersed and sampled so as to simulate successfully the behavior of other materials. That is, could fluorescent particles serve as an atmospheric tracer of 10 microns aerosols.

Phase B consisted of 16 successful or partically successful trials conducted over a five year period, 1961 to 1966. The objective of the Phase B was to supplement Phase A data obtained under stable (inversion) conditions with data obtained under unstable (lapse) and neutral conditions.

All trials were run on the Air Sampling Grid (ASG) at Dugway Proving Ground, a grid that allows vertical sampling to a height of 300 feet and horizontal sampling to a downwind distance of 16 miles. On many trials, downwind sampling was supplemented by both millipore filter and rotorod samplers carried aloft by tethered balloons.

Both this report and its key references have been extracted. (APPENDIX XI) As noted, no recovery data were obtained. However, the scale of testing and methods developed to support these tests make this report an item of permanent interest.

Sections extracted include:

Introduction
Objectives
Method
Results
Analysis
Appendix I - Synoptic Description

REFERENCE 8

<u>Technical Report</u>
AD 873211
ACC ___

<u>C - Series</u>
Date: 690800
Test Series: none

Aerial Herbicide Application Evaluated for Maximum Effect and Minimum Drift.

Murray, James A. and Vanghan, Leland M.
Metronics Associates, Inc.,Palo Alto, CA. Technical Report No. 160.

This report is a synthesis of considerable field and laboratory data on a specific herbicide mix. By using a model incorporating the transport, diffusion and deposition of spray droplets and their biological effectiveness as a function of drop size, the authors established that the number of aircraft and amount of herbicide may be reduced by a factor of five and still achieve the same level of control. The major change recommended is to reduce the spray drop size to yield a mass mean diameter of 120 microns (vs. 400 microns), and to operate when winds are calm.

Only a microfiche copy of this report is available at Dugway, thus a legible extract could not be made. The report is an excellent example of spray cloud modelling used to formulate an operational strategy in aerial application of herbicides.

REFERENCE 9

<u>Data Report</u> <u>B - Series</u>

AD 896 368
ACC 509 448

Date: 680600
Test Series: B 502

Supplemental Tests of Downwind Diffusion from Aerial Line Sources.

Freeze, James E.

The B 502 test series is summarized in AD 865 749L/ACC 529976. This data report contains results of trials B-A1 and B-A2, test methods and procedures in great detail. An extract of the report has been prepared. (APPENDIX XII) It includes details of the two trials and the data obtained. The report is noteworthy because of the inclusion of vertical cloud profiles obtained as far as 16 miles downwind of the release point.

REFERENCE 10

Technical Report	B - Series
AD 813751	Date: 670300
ACC 519203	Test Series: B 502

Survey of the Elevated Line Source. GCA Technical Report No. 66-13-G.

Cramer, H.E., Bass, S., Record, F.A., et al.

GCA Corporation, Bedford, MA. March 1967.

This report is an excellent comparative summary of elevated line source models used in the modeling of transport and diffusion processes as of 1967. The models discussed are identified by their authors and include Palmer and Craw (1962), Elliot and Barad (1964), Vaughan and McMullen (1963), Smith and Hay (1961), and GCA (1967). The results of the Dallas Tower trials and Dugway Proving Ground B 502 tests are analyzed. An extract of the B 502 analysis has been included together with the literature cited. (APPENDIX XIII)

REFERENCE 11

Data Report

C - Series

AD 896 648
ACC 509360

Date: 660800
Test Series: C 679

Feasibility Test of the E44 CS Spray Tank on OV-1 Mohawk Aircraft.

Johnson, Karl R., McIntyre, William C., et al.

On this test program, an irritant agent, CS, dissolved in methylene chloride was sprayed as an aerial line source. Recoveries were estimated by tower "Fly-bys." "Snoot" samplers, all-glass impingers, and cascade impactors were used to estimate particle sizes. Also, a wind tunnel phase was conducted to calibrate samplers before using them in the field.

An abstract of this report has been prepared. (APPENDIX X) It is of interest mainly because it shows the wide disparity of results when samplers with an efficiency that is sensitive to particle size are used.

REFERENCE 12

Technical Memo

C - Series

AD 464208
ACC 63067

Date: 650400
Test Series: none

Analysis of Spray Tests of the E44 Defoliant Tank

Saxon, Richard B.

This report is a reanalysis by a government laboratory of field trails conducted in April 1964 at Mojave, CA. The original report was prepared by the tank manufacturer. The "Dmax" method was used to determine mass mean diameter in the contractor's report. In this report, visual stain sizing is done and the two compared:

Mass Mean Diameter (microns)

Test	Dmax	Visual	Ratio, v/Dmax
M	146	177	1.21
Q	153	179	1.17
R	214	239	1.12

The report concludes that the Dmax method is not reliable at air speeds greater than 200 knots.

This report is of interest mainly because of its recommendation that counting and sizing be used in place of Dmax estimation. In this case, the desired mass mean diameter, 300 microns, was not achieved by the spray system being tested. No extract of this report was prepared.

In the Dugway report on the E44 program (AD 363 0134/ACC 509005) conducted in 1964, all trials gave recoveries greater than 85%. All trials were run under neutral stability conditions at moderate wind speeds at release heights between 240 and 740 feet. Mass median diameters ranged from 202 to 285 microns. Field data were matched to theoretical predictions with excellent results. An abstract of the Dugway report has been prepared. (Appendix IX)

REFERENCE 13

Data Report | C - Series

AD ___
ACC 509105

Date: 650100
Test Series: C 660A

Data Report for Engineering Design Defoliant Trials with the A/B45Y-3 Spray Tank

McIntyre, William C.

This report gives qualitative determinations only based on visual examination of the sampling cards by a trained observer. There was no stain counting or laboratory analysis.

No extract of this report was prepared.

REFERENCE 14

Test Plan

C - Series

AD ___
ACC 530397

Date: 640211
Test Series: C432

Integrated Engineering/Service Test of an Interium Defoliant System Conducted Jointly by the US Army and US Air Force.

McIntyre, William C.

This test plan outlines a three-part test. Part 1- the dissemination tests required for an engineering test. Part 2- Climatic Chamber and Physical tests. Part 3- Service tests. The tank to be tested is described as a modified USN auxilliary fuel tank with a ram-air turbine mounted in front to provide air pressure necessary to disseminate a defoliant mixture from aircraft-mounted spray boom.

The testing outlined in this plan is reported in Final Report of Integrated Engineering/Service Test, AD 363 013L/ACC 509005. May 1965. No extract of this test plan was prepared.

REFERENCE 15

Test Plan

C - Series

AD
ACC 530379

Date: 630924
Test Series: none

Joint Engineering and Service Tests of the Chemical Agent Spray Tank (USAF TMU/28E US Army E43) Phase A: Physical Testing.

Hoeman, Erwin C., Burge, Robert G.

This document details required physical testing, generally MIL-SPEC testing, of an aircraft spray tank. The testing is intended to ensure safety, structural integrity, conformance to design, and military suitability of a spray system designed for high performance jet aircraft.

The testing specified for a military system far exceeds the equivalent commercial specifications. No abstract of this report has been included.

REFERENCE 16

Trial Record | C - Series

AD ___
ACC 509032

Date: 630600
Test Series: C 599

Chemical Dissemination Tests of the Simulant SD-5 Drone (Manned Aircraft). Trial Record DPGTR 333. June 1963.

Authors not listed.

This test series included six simulant trials on which recovery estimates were made. On each 2,000 lbs. of bis were released as an aerial line source. Release heights ranged from 450 to 1,175 feet above the ground; wind speeds between 3.7 and 26.4 mph, with stabilities of lapse, neutral and inversion. Downwind sampling extended to a distance of 4 miles gave recoveries between 56 and 90 percent. Droplet diameter histograms are given. Sampling consisted of printflex cards and filter papers arrayed at 300 foot intervals plus five rows of downwind sampling. An abstract of this report has been made. (APPENDIX V) It includes:

Sampling Array Diagram
Field and Laboratory Methods
Test Results
Recovery Estimates
Droplet Spectra Diagrams

This report does not discuss reliability, accuracy, or precision and is probably only of historical interest. It does contain area assignments for the DPG Downwind Grid. These area assignments were used for many years in calculating horizontal recoveries.

REFERENCE 17

Trial Record | C - Series

AD 390820
ACC 509030

Date: 630500
Test Series: C 582

Phase III Chemical Dissemination Tests of Dummy Fuselage for SD-2 Drone Test, DPGTP 582. Trial Record DPGTR 326.

No author given (McIntyre, William C., and Jackson, Richard I. - D. B.)

This test program included eight trials on which bis was released as a line source by a ram air spray device mounted under the wing of a B-26 aircraft. A square sampling array 4,500 feet on a side was used on the eight trials; there were no downwind sampling lines. Cylindrical samplers wrapped with filter paper were positioned 5 feet above the ground at all sampling positions on the first 5 trials (phase A and B). The simulant trials were flown 288 to 420 feet above ground level at speeds between 319 and 349 knots. Recoveries ranged between 61 and 100 percent within 4,500 feet downwind of the release line. Stability conditions ranged from neutral through inversion at wind speeds between 3 to 13 mph. On trial C-1, the trial giving 100% horizontal recovery, the depositon pattern was contained by the sampling array at the 10 mg/m level.

An extract of this report has been made. (APPENDIX VI) The extract includes:

- Objectives
- Procedures
- Results
- Contour diagram for trial C-1, the 100% recovery trial

This report contains no discussion of accuracy, precision, or reliability and appears to be mainly of historical interest.

REFERENCE 18

Test Plan — C - Series

AD ___
ACC 530381

Date: 630318
Test Series: C 660B

Engineering Test Defoliant Trials with the A/B 45Y-3 Spray Tank.

Authors not given. (McIntyre, William C., and Jackson, R. I. -D B)

This test plan is superceded by ACC 530 382, 21 June 1963. No extract was prepared.

REFERENCE 19

Test Plan

C - Series

AD ___
ACC 530383

Date: 630305
Test Series: C 660A

Engineering Test Defoliant Trials with the TMU 28/E Spray Tank.

McIntyre, William C., Jackson, Richard I.

This test plan was superceded by ACC 530 383, 21 June 1963. No extract was prepared.

REFERENCE 20

Technical Report | B - Series

AD 405 940
ACC 500 705

Date: 630130
Test Series: B 502

Intermediate-Scale Aerosol Cloud Travel and Diffusion from Low-Level Aerosol Line Releases. Technical Report No. 97. January 30, 1963.

Vaughan, L.M. and McMullen, R.W. Aerosol Laboratory. Metronics Associates, Inc., Palo Alto, CA.

The B 502 test program consisted of a series of field tests using fluorescent particles as an atmospheric tracer. The analysis of the first nine trials of the B 502 series are the subject of this report. Meterological conditions ranged from strong inversion to moderate lapse with wind speeds at the release height (150 to 300 feet) ranging from 5 mph to greater than 20 mph.

The sampling array consisted of lines of samplers (rotorods and membrane filters) 5 feet above the ground at one-mile intervals to a downwind distance of 15 miles. Also, there were tower-mounted samplers at 5-foot intervals from 5 to 300 feet on a 300 foot tower, and at 15-foot intervals on 95 foot towers located 1/2, 2, 6, and 10 miles downwind. Balloon-borne samplers were located near these towers with samplers at 75-foot intervals from 175 to 775 feet.

On trials 1 through 5, a single release of yellow FP was made. On trials 6, 7 and 9, both yellow and green FP were released, each at a different altitude. On trial B-8, an aerial release of one color was combined with a ground-level release of the other.

The report contains plots showing actual vs. predicted values for the 15 miles over which the cloud was sampled. Plots of vertical dosages for both rotorod and millipore samplers are also given, together with an analysis of the winds aloft during the cloud transport and diffusion.

An extract of this report has been made giving examples of the dosage field plots on which the analysis was based. No recovery calculations are included in this report. (APPENDIX XIV)

There is a second, related report in which an analysis of the final five B 502 tests may be found. It is AD 474208L/ACC 519279, Further Analysis of Intermediate-Scale Aerosol Cloud Travel and Diffusion Data from Low-Level Aerial Line Release. L.M. Vaughan is author and it was published as Technical Report 117 by Metronics Associates, June 2, 1965. An extract of the charts on which the analysis is based has been included. (APPENDIX XV)

REFERENCE 21

Trial Record

C - Series

AD 359536
ACC 509147

Date: 630100
Test Series: C 607

High-altitude Release Bis Spray Trials with the E29 R1 Spray Tanks. Trial Record DPGTR 324.

Authors not listed.

On the C 607 program, two trials were run, one at a release height of 1,380 feet and one at 710 feet. On both, approximately 730 pounds of bis dyed with du Pont oil red dye were released as an aerial line source using a ram-air spray device mounted on a high performance jet aircraft. Filter paper and printflex cards were arrayed to a downwind distance of 2 miles. Recoveries were 65.7 and 76.8 percent. Winds were 18.8 and 20.0 mph. A mean droplet diameter of approximately 250 microns was estimated. This shows successful use of the methodology developed in DPGR 247, AD 343 004/ACC 500091. It is of interest mainly because of the high recoveries for the release heights involved. An extract has been included. (APPENDIX VII) It includes:

Methods
Grid Array
Test Results
Droplet Spectra Histograms

This report does not discuss accuracy, precision, or reliability and appears to be of historical interest only.

REFERENCE 22

Test Plan

C - Series

AD ___
ACC 501187

Date: 620427
Test Series: C 628

Operational Trials with the A4D Jet Aircraft and Aero 14B Spray Tank, DPGTP 628

McIntyre, William C., Jackson, Richard I.

This test plan specifies test conditions and procedures to be followed on the CW 628 test series. The report is a US Navy report and is not controlled by Dugway Proving Ground. It was not reviewed.

REFERENCE 23

Test Plan

C - Series

AD ____
ACC 501185

Date: 610801
Test Series: C 607

Title: High Altitude Release Bis Spray Trials with the E29R1 Spray Tank. DPGTP 607.

Author: McIntyre, William C., Jackson, Richard I.

This test plan specifies test conditions and procedures to be followed on the CW 607 test series conducted in January 1963 and reported in DPGTR 324, ACC 509 147/AD 359 536, January 1963.

Essential portions of this plan are repeated in DPGTR 324. No extract was prepared.

REFERENCE 24

Memorandum Report
AD
ACC 519100

B - Series
Date: 610302
Test Series: B 502

This memorandum report, Memorandum Report No. 13, was prepared by Metronics, Inc., and reports the results of the first six trials of the B 502 program. The trials were designed to study the vertical diffusion of a particulate cloud (FP) generated from an elevated line source along a crosswind line under stable atmospheric conditions. Surface samples were taken to a distance of 15 miles from the source and vertical samples were taken at three downwind positions, 1/2 mile, 2 miles, and 6 miles. Both millipore filters and rotorods were used to sample the FP cloud. Although the report postulates that rotorod recoveries should be divided by three to be comparable with the millipore recoveries, the division is not carried out; it is explained that rotorod calibration is still being studied.

No abstract of this report was included. Also, the Dugway copy of the report ends with Figure 17 although the text cites figures 18, 19 and 20.

REFERENCE 25

Final Report   C - Series

AD 343 004   Date: 600400
ACC 500091   Test Series: CW 442

Comparative trials of the modified and unmodified Aero 14B Spray Tank, Bis-filled. DPGR 247. Authors not listed. (William C. McIntyre and Richard I. Jackson - D. B.)

The CW 442 test series consisted of 7 trials on which 700 pounds of a non-volitile liquid, bis (2-ethylhexyl) hydrogen phosphite, the "Bis" or "bis compound" of Dugway reports, was sprayed from a pressurized spray tank carried by a high-performance jet aircraft. Sampling was conducted on a dense inner array with sampling at 100-foot intervals. Downwind sampling was conducted to a distance of 9100 feet (Delta road of Downwind Grid). Vertical sampling, at 5 feet above ground was also carried out. At all horizontal, ground-level sampling positions, both filter paper samplers for mass recovery and printflex cards for droplet stain sizing were laid out. Both were backed by stainless steel sample holders. The vertical samplers consisted of pairs of 2.69-inch cylinders (beer cans) wrapped either with filter paper or a printflex card.

Spray accountancy estimates within the sampled area (9200 feet downwind of the release line) ranged between 66 and 86 percent, with a mass mean diameter of approximately 275 microns. Wind speeds ranged between 10 and 22 miles per hour, temperatures between 51 and 75°F, with stability regimes of lapse, neutral and stable. (These trials were the test series that established bis as the simulant of choice for non-volatile liquid spray testing at Dugway. Also, the "largest-smallest" techniques of droplet diameter estimation developed by Dr. Richard I. Jackson was first used extensively on this test series. - D. B.)

An extract of this report has been made. (APPENDIX VIII) It includes:

Materials and Methods
Results
Discussion (mass-droplet spectra estimates)
Prediction Reliability
Droplet Diameter Spectra.

This report contains an excellent discussion of state-of-the-art spray cloud evaluation in 1960. In the absence of todays automated devices, an excellent empirical approach to spray cloud assessment is given. Charts are given of "percent recovery vs. downwind distance". Such plots likely should be prepared on all spray programs and made part of the spray program data file.

REFERENCE 26

<u>Test Plan</u> | <u>C - Series</u>

AD -
ACC 528551

Date: 590302
Test Series: C 442

Comparative Bis Spray Trials.

McIntyre, William C., Jackson, Richard I.

Test Plan and one amendment to the CW 442 test plan, specifying test conditions and procedures to be followed on the CW 442 test series reported in DPGR 247 April 1960, ACC 500091/AD 343 004. Essential portions of this test plan are repeated in DPGR 247. No extract was prepared.

REFERENCE 27

B - Series

AD 896 496L
ACC 500536

Date: 581000
Test Series: BW 418

Dugway Proving Ground Trial Record DPGTR 248, BW 418, Phase A, Trials A-3 and A-4. October 1958.

No author given.

On the two trials here reported, a biological simulant, BG, was released from both wing tanks of a high performance jet aircraft. Sampling was conducted on a 300 foot tower to measure the vertical profile of the cloud. Downwind sampling at the 5 foot level was conducted for 15 miles downwind. On both trials, wind speeds were approximately 14 mph at release height. Both trials were run with atmospheric inversion prevailing. All sampling equipment appears to have functioned satisfactorily. On both trials, field meteorology measurements were extensive. Wind streamlines were prepared at 15 minute intervals to assist the test officers in determining sampling times. The effort proved satisfactory, and on both trials, the cloud was sampled throughout cloud passage.

An extract of this report has been prepared. Typical cloud streamline plots are included. (APPENDIX XVII)

REFERENCE 28

Trial Record | B - Series

AD 896563
ACC 500537

Date: 580100
Test Series: BW 418

Field Evaluation of a BW Aerial Spray System, Phase A, Trials A-1 and A-2. October 1958, with undated errata sheet, ACC 500547.

No authors given.

Two tower "Fly-by" trials were conducted in August 1958 in which two biological simulants, BG and SM, were released upwind of a 300 foot tower by a pressurized spray tank flown aboard a high performance jet aircraft. No vertical recovery estimates all given. Wind speeds fell between 10 and 20 mph; instrument malfunction rate was high. The trials are noteworthy because the vertical distributions for both simulant materials are quite symmetrical, conforming well with theory. Although the mix disseminated consisted of droplets generally less than 10 microns the report is a good example of the use of tower "Fly-by" tests used to characterize spray tank dissemination characteristics.

An extract of this report has been made giving general test information together with BG and SM vertical sampling data. (APPENDIX XVI)

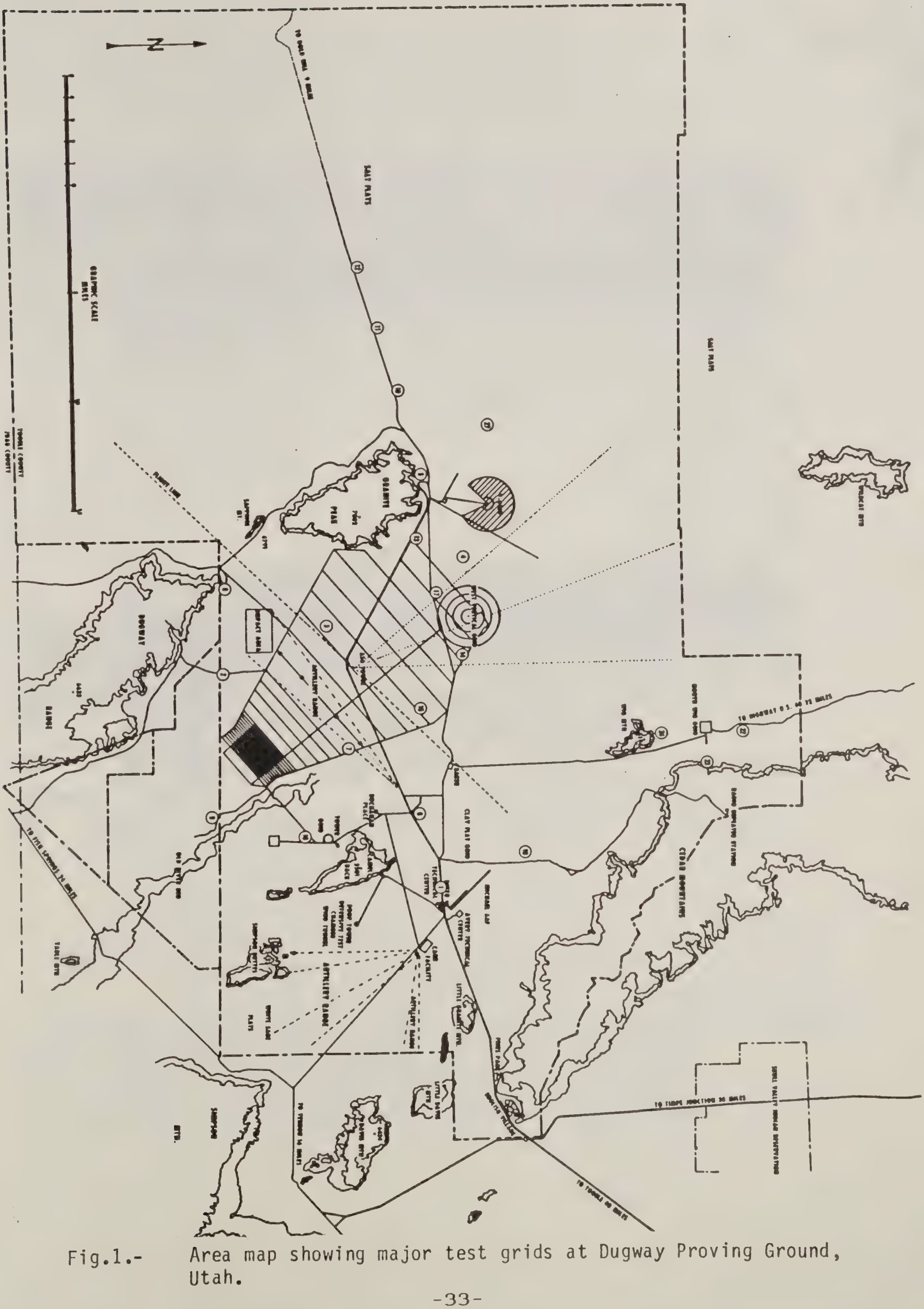

Fig.1.- Area map showing major test grids at Dugway Proving Ground, Utah.

Fig.2.- Downwind Grid. The Downwind Grid has been used extensively in aircraft spray testing since its construction in 1954. It was built on a southeast to northwest center line to match prevailing winds and extends northwesterly for 13 miles. The grid is three miles wide at southeast and nine miles wide at its northwest boundary.

Fig.3.- Downwind Grid looking northwest. A dense array is located on the south boundary of Downwind Grid known as Target "S", the World War II designation for the area. In the dense array access roads are located every 1/10 mile. Downwind sampling roads are spaced at 1/2 mile intervals for the first two miles and at 1 mile intervals for the next 9 miles.

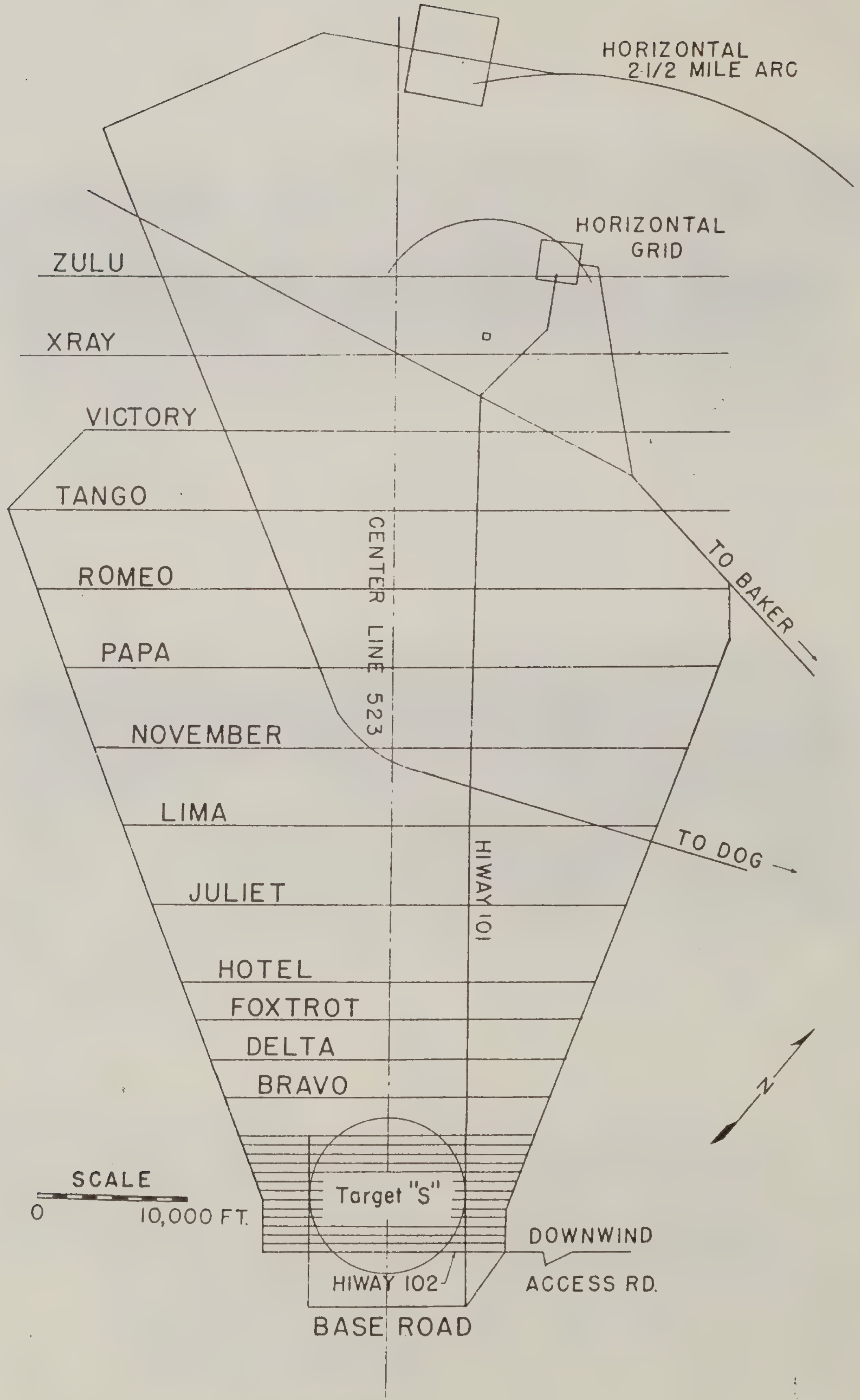

Fig.4.- Schematic outline of Downwind Grid showing downwind sampling lanes.

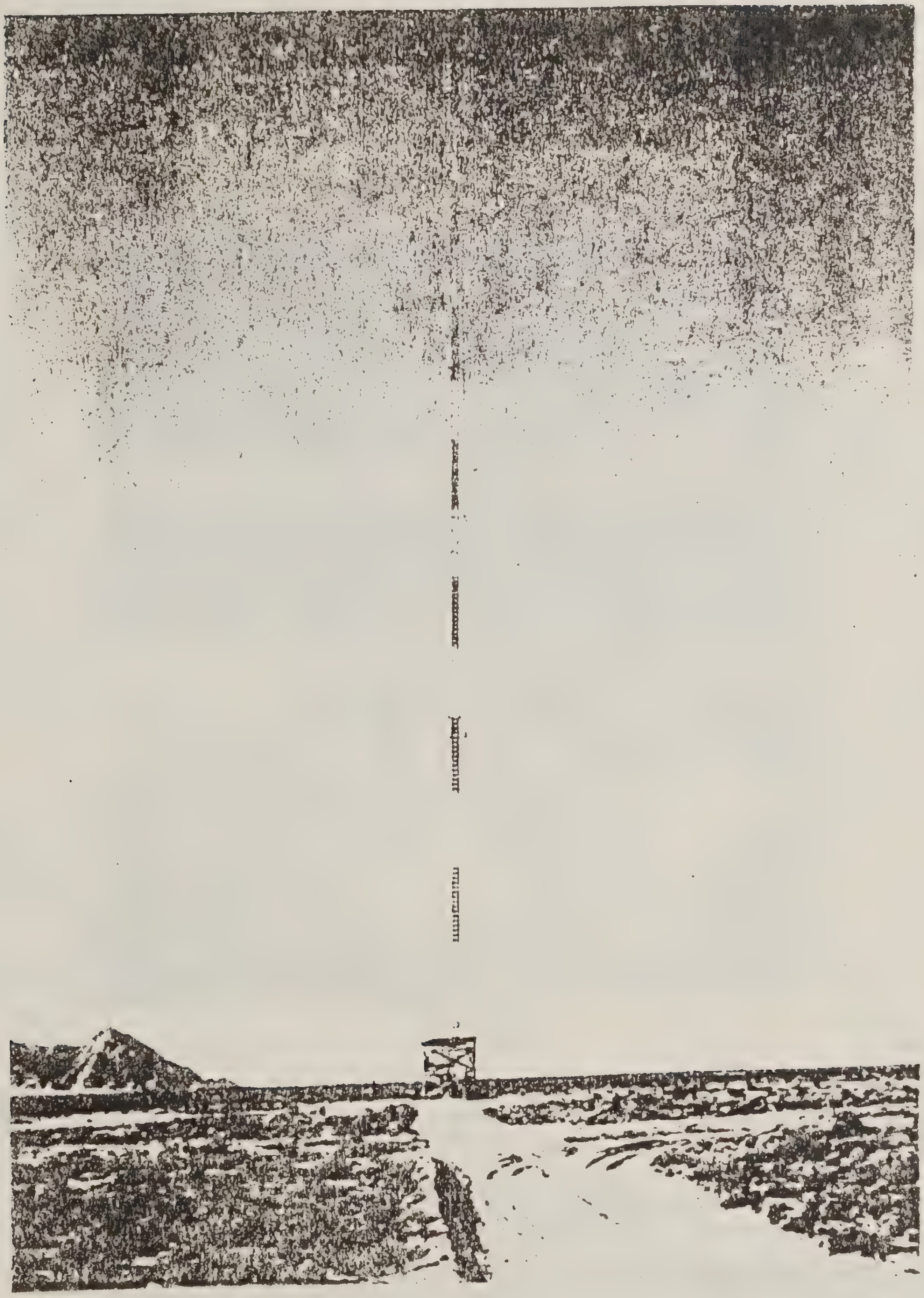

Fig.5.- The Aerial Spray Grid (ASG) showing its 300 foot tower.

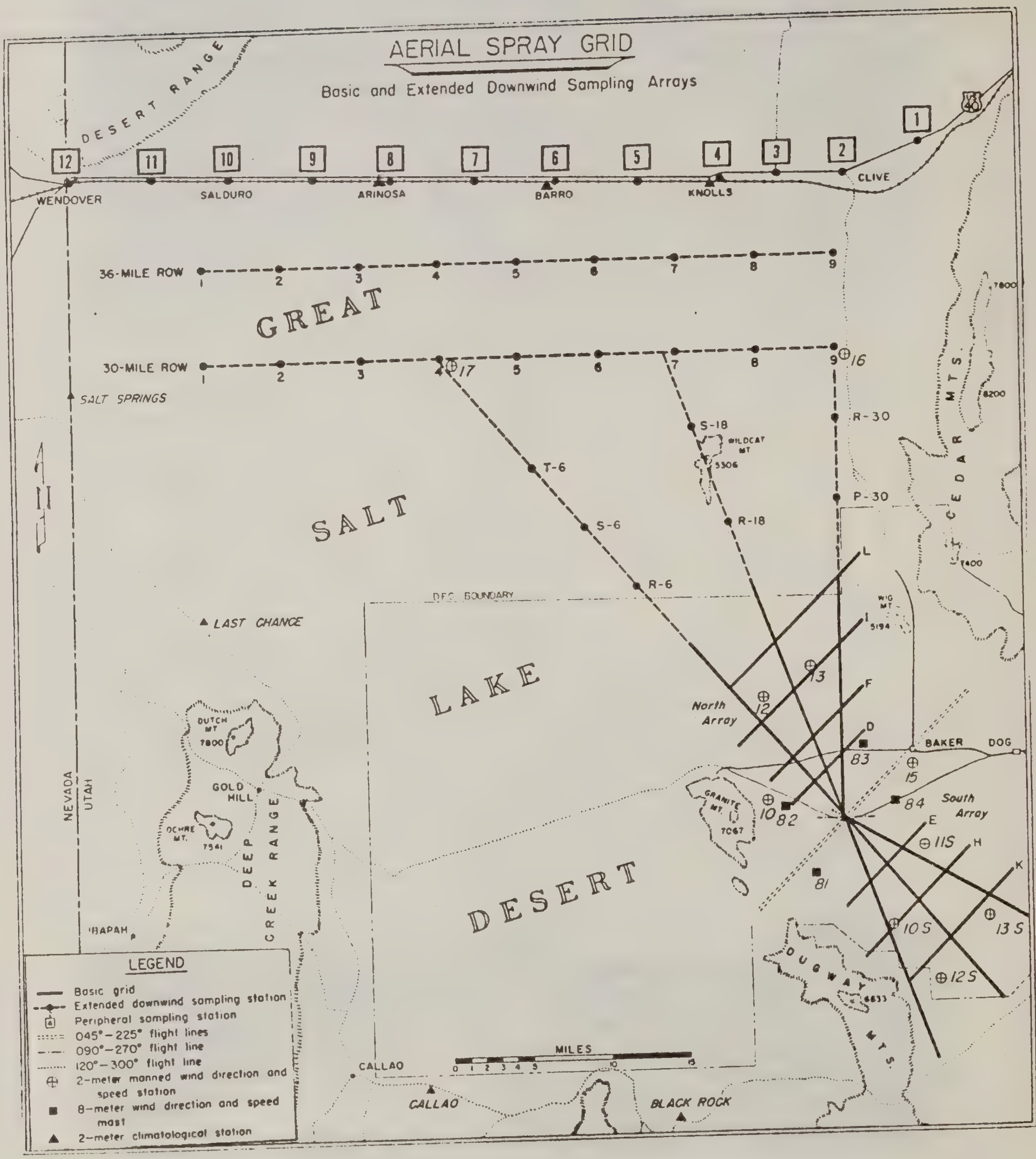

Fig.6.- Schematic outline of the Aerial Spray Grid. The highway to the north is now I-80. The 300-foot tower is near the centerline and November road of Downwind Grid, Fig.4. Sampling on the tower is accomplished by means of a vacuum line that can be raised in 10-foot sections. Samples can be drawn every five feet. The tower vacuum line is driven by a 132 CFM pump and is raised up the tower by an electric hoist.

Fig.7.- A photograph of a five-foot sampling tower used extensively on aerial spray testing. The samples in the foreground consists of a printflex card and three filter papers stapled together. Both are held by a stainless steel backing plate. These plates nest without touching in the sample handling boxes. The cylinders are wrapped with either printflex or filter paper and are positioned at five feet and 18 inches. On occasion, a smaller cylinder such as a pipe-cleaner wetted in a non-volitile solvent was also used.

Fig.8.- A rotorod sampler showing an H-shaped rod in place. The Rotorod sampler consists of a chromel-ribbon wire 0.0159 inches by 0.065 inches, bent into a H-shape and mounted on a small 12 volt DC electric motor. Power for this motor is supplied by small dry cell batteries. The H-shaped rod measures 4 3/4 inches in overall length with each arm of the "H" measuring 1 3/16 inches in length. The rod rotates at a speed of 2,400 rpm, sampling 40 liters of air per minute. As the rod rotates, fluorescent particles are collected and retained on the leading edge. These particles are analyzed in the laboratory by use of a microscope and ultraviolet light. The Rotorod sampler may also be used for vertical sampling by attaching the instruments at intervals along the length of cables holding tethered balloons. The sampler has a 57.3% efficiency with particles in the 1 to 5 micron size range.

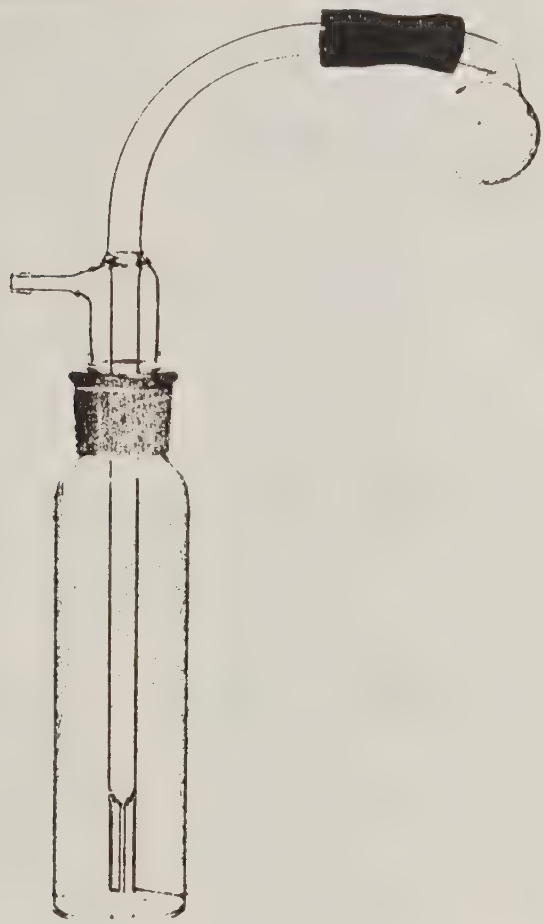

Fig.9.- All-glass Impinger (AGI) with a preimpinger in place. The Biological Impinger - Pre-impinger is a collecting device used to sample viable biological particulates. Generally the sampling mechanism is manufactured of glass but may also be made of nylon. The pre-impinger is always glass. The all-glass impinger is 10.5 inches high, 1 1/2 inches in diameter and weighs 4.4 ounces. The nylon impinger has a height of 9.25 inches, a diameter of 1.5 inches, and weighs 1.8 ounces. The pre-impinger bulb is 1.25 inches in diameter and has a stem 1 inch long and 7/16 inch in diameter. It weighs 0.42 ounces.

GLOSSARY

TERM	DEFINITION
	A
α	Lateral diffusion coefficient; crosswind diffusion coefficient. (Note: all symbols used in mathematical expressions are defined in each appendix as they appear.)
Aerosol C-61	A cationic surface active agent manufactured by American Cyanamid Company. In aircraft spray at Dugway, it was used to wet fluorescent particles suspended in a carrier. A typical recipe is given on pages II-51 ff.
AGI	All-glass impinger. A device designed to remove small solid aerosol particles from a moving air stream by impingement on the bottom of a glass cylinder. The "all glass" designation differentiates the AGI from models incorporating parts made of metal or plastic. The AGI in common use at Dugway in the 1950-70 era is shown in Figure 9. When an AGI is used with preimpinger (q.v.) and operated at critical air flow rate, the device samples a narrow size range of solid aerosol cloud.
Arlacel 83	A cationic surface active agent made by the Atlas Chemical Company. See pages II-51, ff.
ASCAS	An acronym for Dugway's Automatic Spot Counter And Sizer instrument.
AGS	An acronym for Dugway's Aerial Spray Grid. This grid is shown in several of the appendices, e.g., page XI-6.
	B
β	Vertical diffusion coefficient.
BG	An acronym for <u>Bacillus</u> <u>Subtilis</u> var. <u>niger</u>. In early reports the organism was called <u>Bacillus</u> <u>Globigii</u>. BG is endemic in most

areas and has been used in studies of the transport and diffusion of bacterial aerosols.

bis — A short name for bis-2 (ethyl hexyl) hydrogen phosphite, a relatively non-volatile organic liquid used at Dugway 1958 to the present. Bis was found to be easy to dye and analyze. Use of respirators and gloves by field personnel is advised on bis spray programs.

C

Cascade Impactor — An aerosol sampler in which impaction of a sample of an aerosol cloud takes place in four or more stages. The sample enters the sampler at a low velocity, impacting larger particles on the first stage of the device. The velocity is increased at each stage, "cascading" the sample and impacting smaller and smaller particles at each stage. In Dugway's experience, the Cascade Impactor was best suited for use in laboratory studies. The efficiencies of such impaction devices vary with the nature of the aerosol being sampled, an observation demonstrated by the recoveries shown in Appendix X.

D

deg — Degree

° — Degree symbol used in reporting temperature measurements.

ΔT — "ΔT." A convenient term for the average difference in air temperature measured at two heights above the ground. In Dugway reports it is most often expressed in Fahrenheit degrees (F°) but is converted to degrees Celsius when used in calculations. It is used as a measure of atmospheric stability near the ground. Although the heights at which ΔT measurements were to be made were standardized by US, UK and Canadian testing groups in the early 1950's, the values selected in the preparation of summary tables vary widely. In US, UK and Canadian reports, the convention is to subtract the lower reading from the higher,

that is, T(0.5m - 16m) means the temperature at 16 meters minus the temperature at 0.5 meters. That convention yields a positive quantity for inversion conditions and a negative quantity for lapse. In some European countries, the order of subtraction is reversed.

Downwind Grid — A permanent field test array at Dugway used extensively for spray testing. It is shown schematically on page II-2.

Dosage, Dose — The use of these words in the field test reports reviewed was almost always confusing. Most often, the words are being used to contrast sampling techniques and bear no relationship to the dose <u>vs</u>. dosage contrast of the pharmacist. On occasion they are used interchangeably, a fact of life noted in the newer dictionaries. On a field test, a sampler that integrates concentration (mg/m) over time (min) yields a dosage (mg -min/m). A sampler that measures only a contamination level (mg/m) yields a dose. In the context of predictive models, dosage is defined as the concentration - time integral and the term dose gives way to concentration, or, on occasion, deposition.

du Pont Oil Red — An oil soluble red dye manufactured by the du Pont Company and having a color index of 258. The use of this dye at Dugway dates to World War II. At that time, it was the dye commonly used in leaded gasoline, was readily available during a period of war-time shortages, and gave a droplet stain that did not fade in the bright desert sun.

E

Eff, $\overline{Eff}$ — Dissemination efficiency, average dissemination efficiency; generally expressed as the ratio of measured source strength (Q) to the product of total fill and purity of fill. Eff, $\overline{Eff}$ are sometimes seen as subscripts.

F

Fill — The material released on a field test, the mix. Occasionally the fill is referred to as the agent being tested or evaluated. The Forest Service uses the term tank mix.

Filter Paper — Filter paper laid out at ground level or wrapped around cylinders is used at Dugway as a mass sampler when non-volatile liquids are being tested. Three sheets of filter paper are stapled together, effectively trapping droplets as large as one mm on the fibers of the three sheets. The filter paper used is Whatman number 1.

Fly-by — A term used to identify a common type of aerial spray test in which the aircraft "flies by" a vertical tower to provide an estimate of spray tank efficiency.

Fuel oil — A common carrier of insecticides in aircraft spray work. At Dugway, No. 2 fuel oil was most commonly used. Typical physical properties can be found on page III-27.

FP — Fluorescent particles, or, fluorescent pigment particles, a term more technically correct but rarely used. Testing using fluorescent particles as a tracer material is discussed in Appendices XI, XII, XIII, XIV, and XV.

Ft — Feet

G

Gal/min. — Gallons per minute. A measure of flow rate.

GC — Gas chromatograph or gas chromatography.

Gm/sec — Grams per second. A measure of flow rate.

H

H — Height, generally with a subscript indicating the height being discussed, e.g. H_M.

H_M	Height of the mixing layer of the atmosphere.
H_R	Height of release. The height of the aircraft at the time a spray device was functioned.
H-shaped Rotorod	A rotating sampling device developed by the Chemistry Department of Sanford University and later manufactured and marketed by Metronics, Inc. An H-shaped Rotorod is shown in Figure 8.
HZ	Horizontal recovery. The amount of spray recovered on horizontal sampling array, most often at ground level.
	<u>I</u>
Inert cylindrical samplers	Originally, the inert cylindrical samplers were beer cans wrapped with either a printflex card or three filter papers. Glass jars of the same diameter (2.69-inches) were later used.
	<u>K</u>
Kg	Kilogram.
Kytoon	A large Helium-filled balloon used to lift samplers such as rotorods aloft.
	<u>L</u>
1	Liter.
1/m	Liters per minute.
1/sec	Liters per second.
	<u>M</u>
m	Meter.
m/sec	Meter/second.
mg	Milligram.
μ	Micrometer.

MMD	Mass median diameter. A statistic used to characterize droplet sprays and calculated so that the spray is divided into two parts, with 50 percent of the mass comprised of droplets with diameters less than, and 50 percent with diameters greater than, the mass median diameter. MMD and Volume Median Diameter (VMD) are equal when the specific gravity is equal to 1.
MPH	Miles per hour.
	<u>N</u>
NMD	Number median diameter. A calculated droplet diameter that divides a spray cloud into equal groups, half the droplet diameters are less than the NMD and half the droplet diameters are greater than the NMD.
	<u>O</u>
Oil red dye	See du Pont oil red dye, above.
oz/a	Ounces per acre. A measure of flow rate.
	<u>P</u>
p	Power-law exponent of the vertical profile of the average wind speed. In Appendix IX p is a dimensionless parameter proportional to droplet settling velocity.
Petri dish	A small shallow dish of thin glass or plastic with a loose cover used for bacteriological cultures. (Named after a German bacteriologist, Julius R. Petri.)
Percent (%) recovery	The percentage of the total fill or mix that can be accounted for or recovered within the sampling array. Percent recovery is often interchangeable with Efficiency and Recovery Rate.
Point count	A technique of summing sampler recoveries at each point on the array multiplied by the area assigned to each sampling position so as to yield total horizontal % recovery.

Printflex card — Printing cover stock used to sample droplet stains of dyed liquids. "Printflex" cards were adopted by Dugway in ca 1952, following the lead of the Suffield Experimental Station, Alberta, Canada. Hilburton, et al, (Aerial Control of Forest Insects in Canada, M.C. Pribble, Ed., Dept of the Env., Ottawa,Canada, 1975) described Printflex paper as "a casein-sized and mineral-filled calendered printing cover stock" (p. 60). (At Dugway, printflex cards were purchased under Federal Stock Number FSN 7530-000-0154 Pages, offset, coated cover, Printflex, substance 80. Mead Paper Co., Chillicote, Ohio.) Matched against Dugway test conditions, Printflex has proved an ideal sampler; (1) It could be obtained in large lots, minimizing lot-to-lot variations over a period of several years; (2) at Dugway, samplers are often laid out in the early morning hours and are exposed to the heavy frosts of the high desert country and Printflex could still be analyzed for stains after being exposed to frost; and, (3) Printflex was sturdy enough to stay in place when placed in a stainless steel holder, and not be blown away by Dugway winds.

Q

Q or q — Accepted algebraic notation for source strength, i.e., the total amount of mix of material released. In some reports Q is used for total source strength, q for incremental source strength such as the source strength of one sampling row.

R

RH, $\overline{RH}$ — Relative humidity, average relative humidity.

Recovery — The ratio of spray recovered within the sampling array to the amount disseminated. In Dugway reports, the term used is percent recovery, q.v.

Rotorod — A sampling device developed by the Chemistry Department of Stanford University and later manufactured and marketed by Metronics, Inc. A Rotorod sampler is shown in Figure 8.

S

σ_A	Standard deviation of the azimuth wind angle, often in radians.
σ_E	Standard deviation of the wind elevation angle, often in radians.
σ_x	Standard deviation of the alongwind concentration or dosage distribution.
σ_y	Standard deviation of the crosswind concentration of dosage distribution.
σ_z	Standard deviation of the vertical concentration or dosage distribution.
SM	An Acronym for <u>Serratia</u> <u>marcescens</u>, a bacterium used in studies of the behavior of airborne organisms.
Snoot sampler	A plastic conical sampler designed similar to a Fisher Scientific isokenetic stack sampler. The inlet opening and conical angle were selected to approach isokenetic flow for the predicated mean wind speed.
Spread factor/Stain factor	Both terms have the same definition. Dugway reports generally use spread factor and define it as the coefficient (slope) in the drop-stain relationship, with droplet diameters plotted as Y in the regression. Thus, in Dugway reports, the spread factor is always less than unity. For many years, the Y-intercept was 40 microns, suggesting that droplets with a diameter of 40 microns or less left no stain. Since the fibers in Printflex cards are reported to be about 20 microns, the intercept value would suggest that two or more fibers must be wetted to leave a visible stain.

T

T, $\overline{T}$	Temperature, average temperature. The text must be consulted to determine the temperature scale used.
TOF	Tri-octyl phosphate. An organic solvent of low volatility used in spray test.

U

U, $\overline{U}$	Wind speed, average wind speed. The text must be consulted to determine units.
U-shaped Rotorod	A Rotorod sampling device shaped like the letter U. The drive shaft connecting the sampling device and the motor is mounted at the center of the U.

V

VT	Vertical recovery. The amount of spray recovered on a vertical sampling array.
V_T	Terminal velocity.
VMD	Volume mean diameter. A statistically derived droplet diameter that divides a spray cloud into equal volumes, one volume having diameters smaller than VMD and one having diameters greater.

W

WS	Wind speed.
WSRH	Wind speed-release height product. A calculation that allows the test director to vary aircraft release height as a function of wind speed so as to locate the pattern of maximum deposition on target.

TEST REPORT EXTRACTS

APPENDIX

I

AD C009 258L
RDTE Project No. 1-MU-7-65710-D-049
TECOM Project No. 2-CO-210-049-001
DPG Document No. DPG-FR-T115A-13

DTC TEST 70-11, PHASE I, SUBTEST 3

EVALUATION OF DELIVERY AND ASSESSMENT TECHNIQUES

FOR

AIRCRAFT SPRAY (SIMULANT) SYSTEMS

FINAL REPORT

BY

WILBERT T. TAYLOR
CECIL O. ECKARD
WILLIAM C. McINTYRE
THOMAS A. SEE
RICHARD B. BLACK

FEBRUARY 1977

U.S. ARMY DUGWAY PROVING GROUND
Dugway, Utah 84022

DESCRIPTION OF MATERIEL

Simulant

Mixtures containing either BIS or TOF, with zinc cadmium sulfide fluorescent particles (FP), Photo Flo,[1] Aerosol C-61[2] or Arlacel 83,[3] and oil red dye were used in the conduct of these trials.

General approximate specifications of the TMU-28/B spray tank are as follows:

Diameter	58 centimeters (23.0 in)
Fin Span	90 centimeters (35.0 in)
Flow Rate	75 liters/second (20 gal/sec)
Fill Capacity (total)	675 liters (178 gal)
Weight (empty)	260 kilograms (573 lb)
Weight (simulant fill)	865 kilograms (1,907 lb)
Electrical Power	25 to 28 volts, DC
Center of Gravity	
Empty	37 millimeters (1.5 in.) aft of the center point between lugs
Full	48 millimeters (1.9 in.) forward of the center point, between lugs

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1 A product of the Eastman Kodak Company

2 A cationic surface active agent made by the American Cyanamid Company

3 A cationic surface active agent made by the Atlas Chemical Company

Table 1. Scope of Test 70-11, Phase I, Subtest 3 (Dissemination Trials of F4-TMU-28/E

Number[a] of Trials	Number of TMU-28/B Spray Tanks	Simulant Used	Purpose
3 (3)	1	BIS	Elevated line source releases of simulant mixtures to determine:
2 (3)	1	TOF	a. Functionability of the re-engineered MLU-40/B cutter/ TMU-28/B spray tank system.
2 (3)	2	BIS	b. Source strength, droplet size distribution, mass calculations and downwind surface deposition density.
0 (3)	2	TOF	

[a] Numbers in parenthesis indicate the number of trials originally planned for this subtest and numbers not in parenthesis indicate the number of trials actually conducted.

DATA ACQUISITION PROCEDURE

Simulant Mixture Preparation

a. The simulants BIS and TOF used in this test were tagged with fluorescent particles (zinc cadmium sulfide) to permit the sampling and assessment of very small simulant droplets up to 15 miles downwind. The preparation of this mixture, additives used, and the allied sampling techniques using rotorod sampling is addressed in a separate report.

b. After notification that the trial would be conducted, the TMU-28/B tank(s) was filled with either the simulant TOF or BIS. The spray tank(s) was weighed for gross weight and then turned over to the Air Force armament crew for loading onto the aircraft.

Aircraft Loading

a. The TMU-28/B spray tank(s) was loaded onto the aircraft by Air Force armament personnel in accordance with U.S. Air Force Technical Orders.

b. In single tank trials, the simulant-filled TMU-28/B spray tank was mounted under the right wing and the full auxiliary fuel tank under the left wing to provide the ballast required for aerodynamic stability.

Spray Release Method

In the single tank trials, the simulant was released at an altitude range of 200 to 800 feet above ground level to obtain a WSRH of approximately 4,000 ± 1,000 feet-knots (see Figure 2). On the dual tank trials, the simulant was released at an altitude of 200 to 1,600 feet above ground level to obtain a WSRH of approximately 8,000 ± 2,000 feet-knots (see Figure 3). The required release height was determined by the Test Officer from a consideration of the mean wind speed obtained from PIBAL data. Flight and aiming point markings were installed before each trial to clearly indicate the line of flight, aiming point, and intended point of initial discharge. The aircraft heading and speed were programmed for 050 degrees and 0.82 Mach (500 KIAS), respectively.

Sampling

a. In each trial, one printflex card sampler was positioned at each of 756 ground sampling positions shown in Figure 4 and at each of the 83 sampling positions shown in Figure 5.

b. Filter paper samplers were positioned on each of 484 positions shown in Figure 4.

c. Rotorod and inert cylindrical samplers were positioned on the primary (Figure 4) and downwind (Figure 5) grids as indicated in Table 2.

These samplers were required to provide data on the downwind drift of small droplets. The information gathered was required for another report and was not used to answer the objective of this test.

Meteorological Procedures:

In each trial, the three 32-meter masts (Towers T-11, T-12 and T-19) and the 96-meter mast (Tower T-00) measured wind speed, wind direction and temperature gradient at the levels specified in Table 3. Standard surface observations were also obtained. PIBAL readings were taken to provide the wind profile needed to determine the W3RH for the aircraft dissemination operation prior to each trial and to define the mesoscale conditions during each trial.

Photographic

Motion picture and still photographs coverage were made for dissemination, aircraft loading and other pertinent aspects of test operations. Following each trial, a microfilm camera was set up in a designated area. The printflex cards were held for a period specified by the laboratory at a temperature equal to or greater than 15.6° C (60° F) after simulant deposition to permit droplet stabilization. The printflex cards were then microfilmed to permit counting and sizing by the ASCAS procedure. When the developed negatives were considered satisfactory for ASCAS processing, the printflex cards were retained and observed to isolate any unusual physical aspects of each trial. The cards were used as standards for qualitative assessment of future trials with BIS and TOF simulants. All negatives were retained for future reference. Data on emission altitude length of dissemination line, discharge point in relation to the target grid, aircraft speed and aircraft heading were obtained using photographic methods.

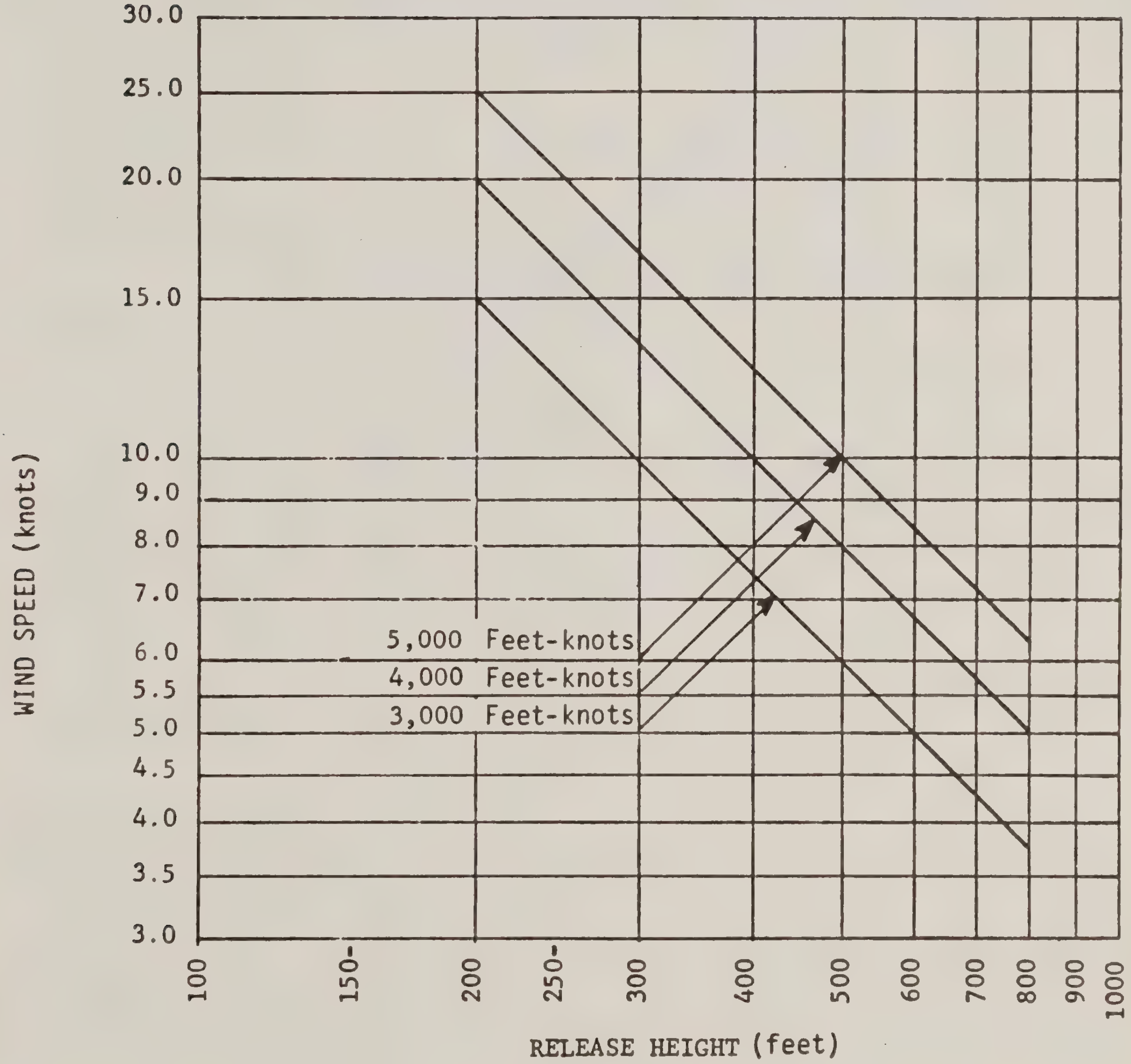


Figure 2. (U) Single Tank Trials - Wind Speed/Release Height (WSRH) (U)

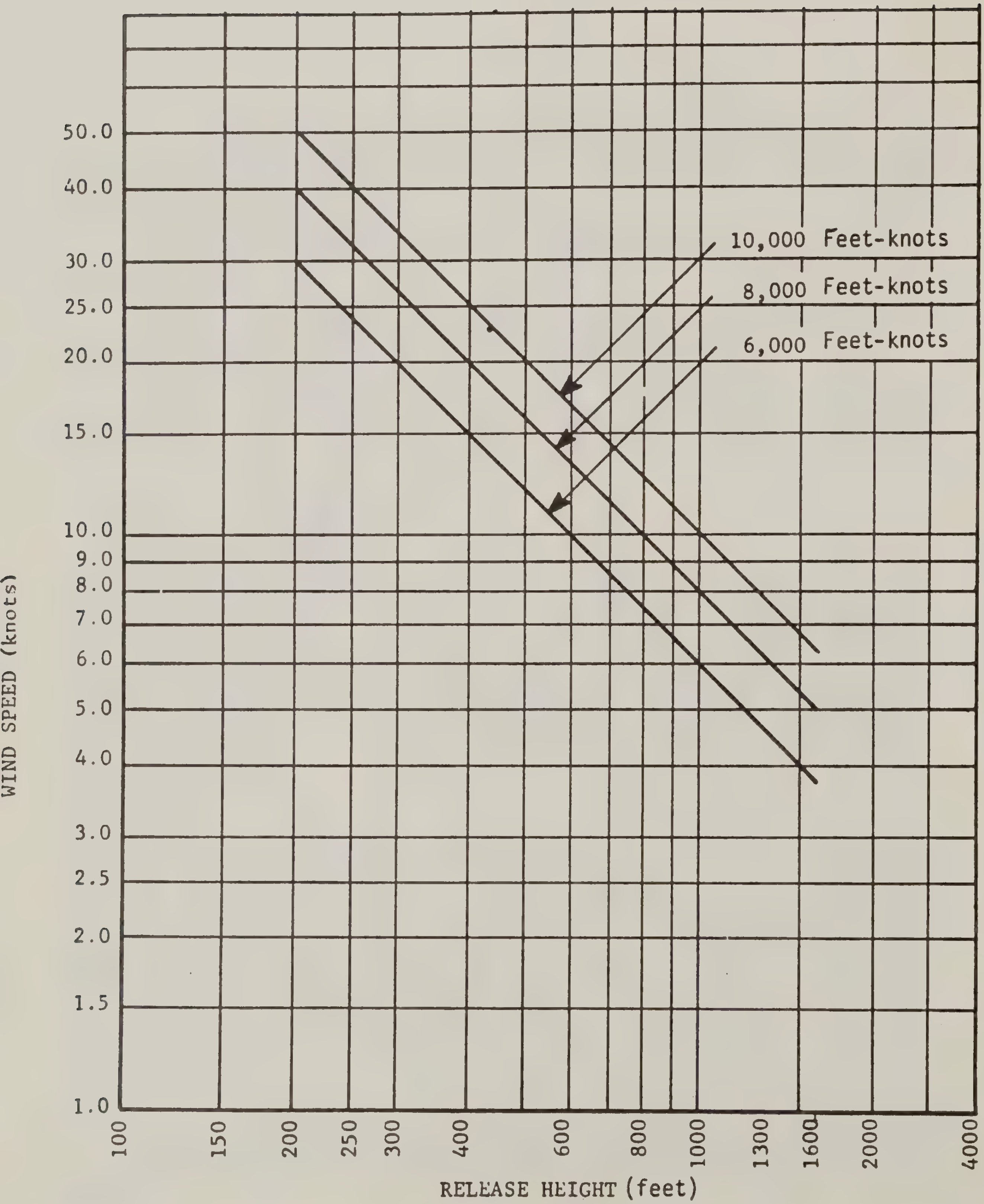
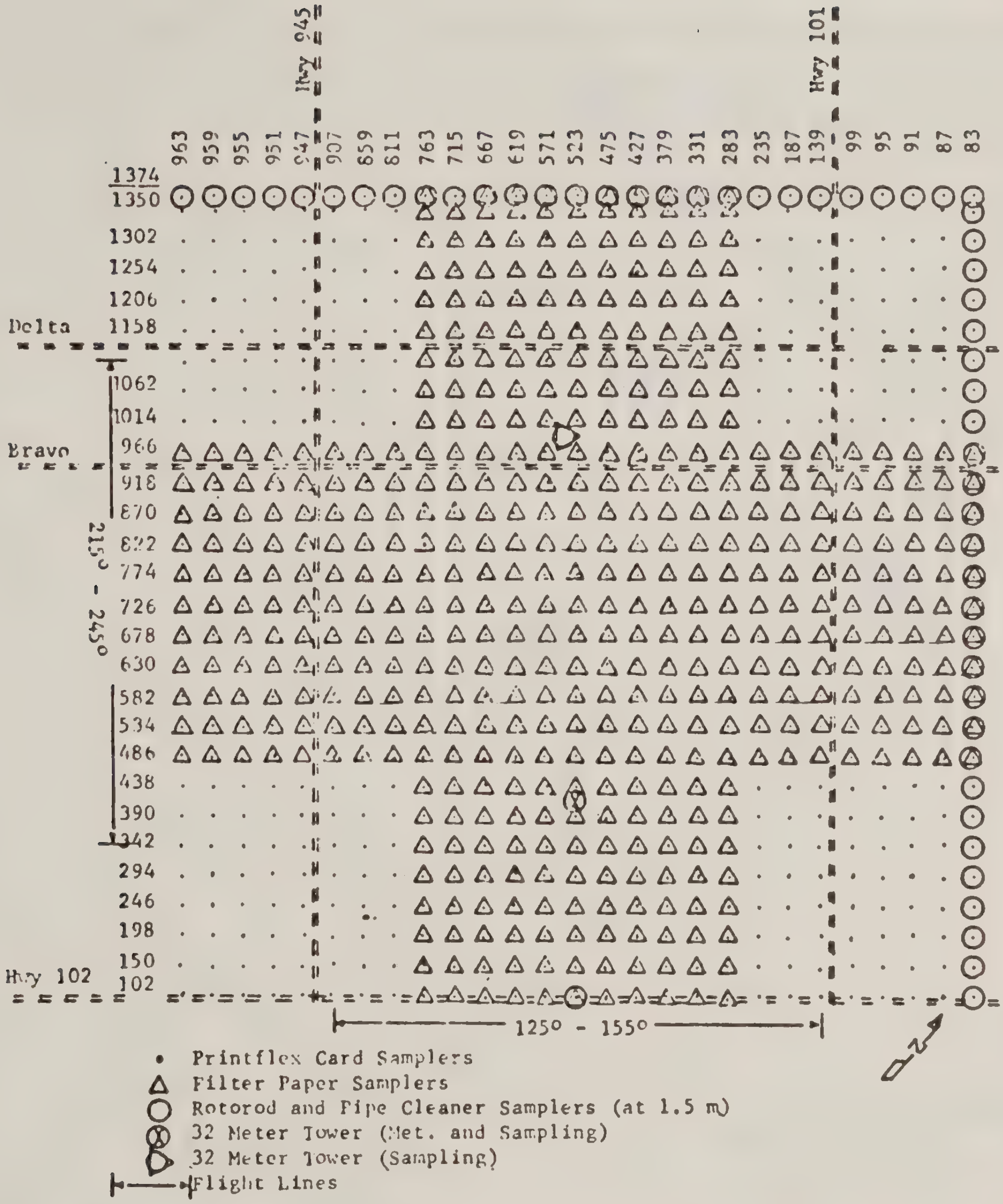


Figure 3. Dual Tank Trials - Wind Speed/Release Height (WSRH)



Each sampling station is 183 m (600 ft) from the adjacent station. Row 1374 is only 91 meters from row 1350.

Figure 4. Sampler Type and Position in the Dense Sampling Array Used in Phase 1, Subtest 3 Trials

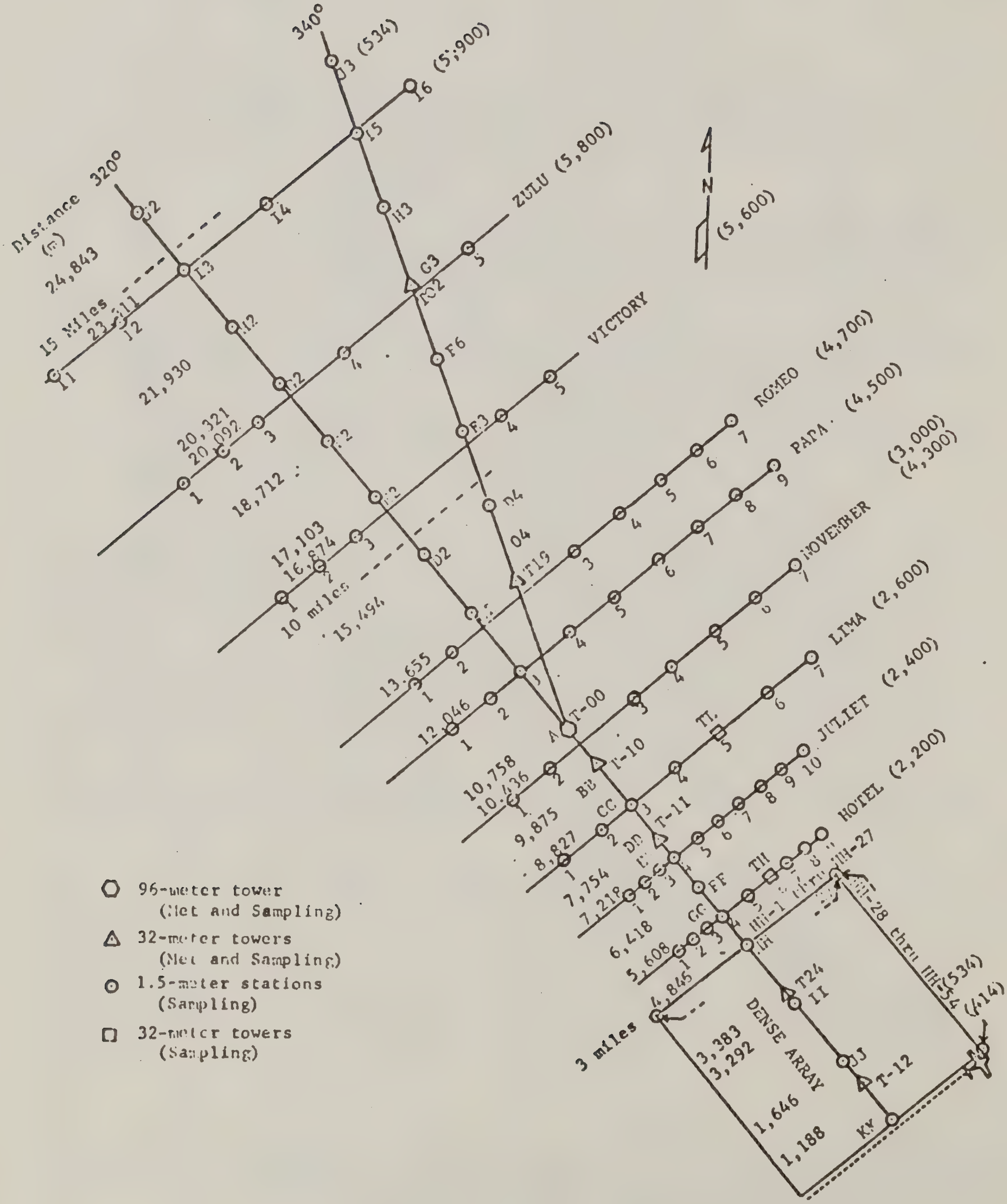


Figure 5. Entire Sampling Array for Phase I, Subtest 3

Table 2. Rotorod and Inert Cylindrical Sampling

Meters	Feet	Towers				Stations (Meters)	
		T-00	T-11 - T-10 T-12 - T-24	T-19	T-02	1.5	32
0.5	1.6	a		a	a	a	
1.0	3.3	a		a	a	a	
1.5	4.9	ab	ab	ab	ab	ab	ab
2.0	6.6	a		a	a	a	
2.5	8.2	a		a	a	a	
3.0	9.8	a		a	a	a	
6.0	19.7	ab	ab	ab	ab		
12.0	39.4	ab	ab	ab	ab		
18.0	59.0	ab	ab	ab	ab		
24.0	78.7	ab	ab	ab	ab		
30.0	98.4	ab	ab	ab	ab		
40.0	131.3	ab					
50.0	164.0	ab					
60.0	196.8	ab					
70.0	229.6	ab					
80.0	262.4	ab					
90.0	295.2	ab					

a = Rotorod sampler
b = Inert cylindrical sampler (pipe cleaner).

Table 3. Meteorological Instrumentation

Height (meters)	Towers			
	T-12	T-11	T-00	T-19
0.5	f	f	f	
1.0	f			
2.0	cdf	cdf	cdef	cd
4.0	f			
8.0	cdef		cdef	
16.0	cdf	f	cdf	
32.0	cdef	cdef	cde	cde
48.0			cdf	
64.0			cdef	
80.0			cdf	
96.0			cdef	

c = wind direction
d = wind speed
e = vertical component of wind direction
f = temperature gradient (0.5m reference)

2.5.2 Aircraft TMU-28/B System Delivery Results

An F100 aircraft was used in Trials 1 through 4 and a F4C aircraft was used in Trials 5 through 7. The gross weight of the TMU-28/B tank was restricted to 1,450 pounds when the F100 was used. A summary of operational and simulant delivery data are contained in Table 5. TMU-28/B tanks prepared for loading are shown in Figure 7. A F4 TMU-28/B system in operation is shown in Figure 8.

2.5.3 Meteorological

A summary of the meteorological conditions prevailing during each dissemination trial is presented in Table 6.

2.5.4 Simulant Recovery

The amount of simulant recovered as ground level deposition on the primary target array was estimated using the point-count technique. This is a technique of assigning a fixed area to each sampling station and assuming that the amount of simulant recovered at each station is representative of the assigned area. Summation of the simulant recoveries for all stations receiving simulant deposition yields a liquid recovery for the target area. The liquid recovery divided by the amount disseminated yields percent recovery.

A summary of simulant recovery for each trial is contained in Table 7. The amount of simulant collected at each sampling station (in mg/m^2) and the amount of simulant recovered for each assigned area for each trial is contained in Appendix A.

2.5.5 Dissemination Flow Rates

a. The rate of dissemination (DR) is related to incremental distance (D) along the spray release line as the flow rate (FR) of a spray tank is related to aircraft speed:

DR: D (feet) :: FR: Aircraft Speed (ft/sec)

b. The mass of simulant recovered on each sampling line perpendicular to the spray release line was estimated.

c. The mass on each perpendicular sampling line was cumulated and the sum of the cumulated line values were used to estimate total mass recovered on the sampling array.

Table 5 . Agent Delivery Data for Phase I, Subtest 3

Trial No.	Date	Aircraft			Spray Tank - Simulant fill				
		UTM Heading (°)	Speed (knots)	Release Height (meters)	No. Tanks (Fill Status)	Gross[a] Weight Kilograms	Net Weight (kg)	Residual Grams	Disseminated Kilograms
1	0707 7 Jun 72	050	554	70	1 - Partial	658 (1,450 lb)	BIS - 406	227	406
2	0849 27 Jul 72	049	556	218	1 - Partial	658 (1,450 lb)	TOF - 406	227	406
3	0738 17 Aug 72	050	536	104	1 - Partial	658 (1,450 lb)	BIS - 406	917	405
4	0910 22 Sep 72	051	554	130	1 - Partial	658 (1,450 lb)	TOF - 406	917	405
5	1211 30 Nov 72	051	575	110	1 - Full	870 (1,918 lb)	BIS - 618	2,041	616
6	1010 31 Oct 73	051	540	145	2 - Full	1678 (3,699 lb)	BIS - 1,114	0[b]	563.6
7	1432 30 Nov 73	053	528	129	2 - Full	1722 (3,796 lb)	BIS - 1,226	1,360[c]	858[c]

[a]An F100 aircraft was used on Trials 1-4 and the gross weight of the spray tank was restricted to 658 kilograms or 1,450 pounds. An F4C aircraft was used on Trials 5-7 and no weight restriction was imposed.

[b]On Trial 6, one spray tank did not function during the test, no residue was found in the tank that functioned properly. The second tank filled with 610 kilograms (1,346 pounds) of BIS was functioned over the safety area.

[c]On Trial 7, the first tank functioned properly but a 4 second delay occurred before the second tank functioned. The amount disseminated over the target was one full tank plus approximately 40 percent of the second tank fill.

Table 6 (U). Summary of Meteorology Data for 70-11, Phase I, Subtest 3 (U)

Trial No.	Date	Time	2-Meter Wind Speed and Direction		8-Meter Wind Speed and Direction		16-Meter Wind Speed and Direction		32-Meter Wind Speed and Direction		Mean Wind Speed[a] (m/sec)	Air Temperature (°F)	Relative Humidity (%)	Temperature Gradient (0.5 to 4.0 m) (C°)
			m/sec	(°)	m/sec	(°)	m/sec	(°)	m/sec	(°)				
1	7 Jun 72	0707:43 MDT	4.7	164	6.5	161	7.4	162	8.7	156	8.7	62.0	60	+ 0.3
2	27 Jul 72	0849:20 MDT	2.0	147	2.5	141	2.6	145	2.7	137	3.0	75.0	30	- 1.5
3	17 Aug 72	0738:43 MDT	4.1	162	ND[b]	ND	7.1	160	8.7	156	9.8	66.0	23	0.0
4	22 Sep 72	0910:44 MDT	ND	ND	ND	ND	ND	ND	ND	ND	8.0[c]	62.0	37	+ 1.0
5	30 Nov 72	1211:46 MST	6.8	159	ND	158	6.1	162	9.0	163	8.0[d]	43.5	50	0.0
6	31 Oct 73	1010:38 MST	ND	ND	ND	ND	ND	ND	ND	ND	4.0	55.9	29	-0.8
7	30 Nov 73	1432:30 MST	ND	ND	ND	ND	ND	ND	ND	ND	4.5	56.5	52	ND
8														

[a]Mean wind speed is from ground to release height and was estimated using droplet vectors, PIBAL data, and profile data from Tower 12.

[b]ND denotes no data.

[c]Met Tower 12 inoperative, wind direction 160 to 175°

[d]PIBAL data.

d. The mass on each perpendicular line was divided by the total mass recovered to obtain a percent recovery for each line.

e. The percent recoveries were cumulated and plotted as a function of the distance from the beginning to the end of simulant recovery.

f. The plot was inspected to determine the portion of the curve representative of a straight line (a linear function is representative of constant simulant flow).

g. The percent recovery and distance (on the y and x axes, respectively) were adjusted to the straight line portion of the plot.

h. The precent recovery associated with the straight line divided by the affiliated distance yielded an average dissemination rate of change. The percent recovery associated with the linear portion of the plot was multiplied by the tank fill to obtain total simulant released over the sector of the grid array. The rate of change multiplied by the total mass released on the selected sector gave an estimated dissemination rate (mass per incremental distance) which was converted to volume per incremental distance.

i. The aircraft speed and dissemination rate were entered into the equation and the tank flow rate computed. The spray tank flow rate for each trial is contained in Table 7.

Area Coverage

The area within the primary target grid covered by selected deposition density levels was computed using the point-count technique. A summary of area coverage results is contained in Table 7.

Droplet Spectra

The droplet mass median diameter (mmd) of the ground level deposition pattern on the primary target array was estimated for each trial from the ASCAS and manual droplet sizing data. A summary of these data is given in Table 7. The computational scheme and the complete droplet spectra analysis for each trial are contained in Appendix A. Graphs of drop diameter versus cumulative mass and drop diameter versus percent mass for Trials 5 through 7 are contained in Appendix A.

Table 7 . Agent Dissemination and Recovery for Phase I, Subtest 3

Trial No.	Agent	Mass Median Diameter (microns)	Flow Rate Liters/sec	Amount Disseminated kg	Recovered kg	Percent Recovery	Area Coverage in Hectares for Indicated Contamination Density (mg/m^2)				
							≥10	≥50	≥100	≥500	≥1,000
1	BIS	191	57	406	318	78[a]	461.54	140.47	73.58	6.69	3.34
2	TOF	205	77	406	363	89	715.72	177.26	86.96	3.34	0.00
3	BIS	162	73	405	389	96	687.30	183.95	110.37	0.00	0.00
4	TOF	267	76	405	401	99	729.10	190.64	66.89	0.00	0.00
5	BIS	237	125	616	587	95	569.40	301.01	160.54	13.38	0.00
6	BIS	141	78	564	486	86	461.54	197.33	103.68	10.03	0.00
7	BIS	158	80	858[a]	791[a]	92[a]	983.29	227.33	120.40	13.38	6.69
8											

[a]Based on an estimate of 40 percent of the payload from Tank Number 2 plus all of Tank Number 1 being disseminated of the target grid array.

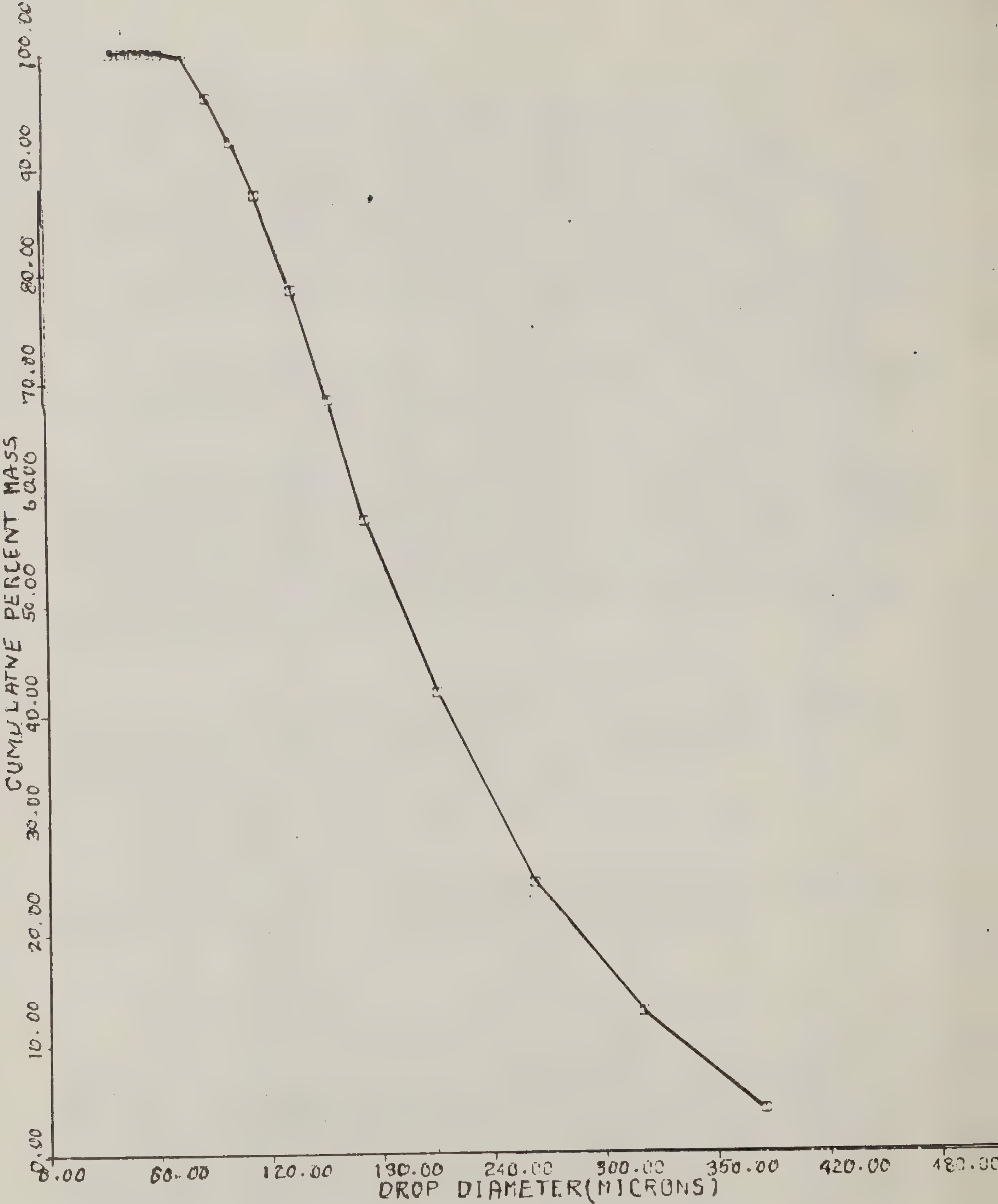


Figure 9. Droplet Diameter versus Cumulative Percent Mass for BIS Simulant, Trial 1

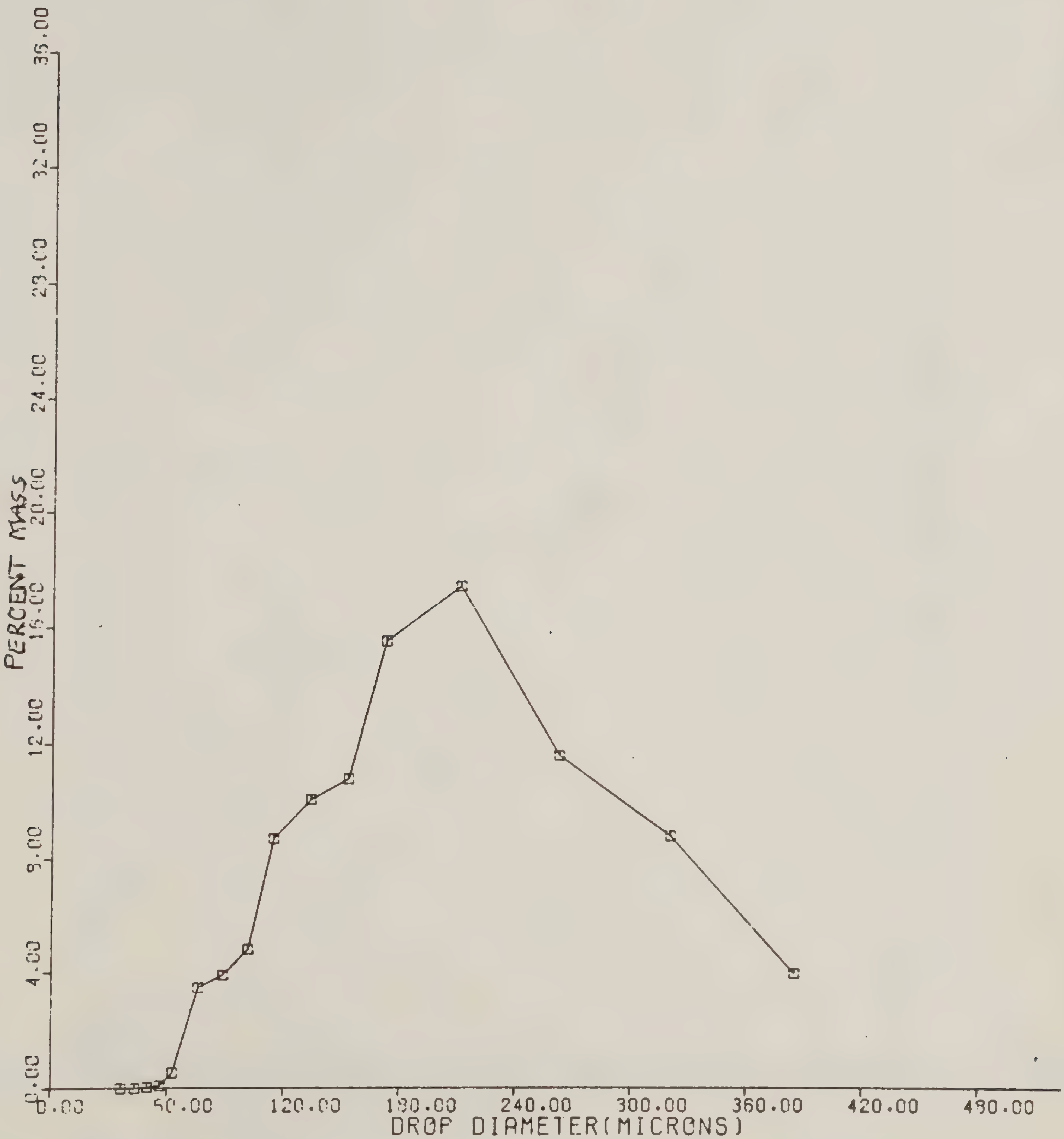


Figure 10. Drop Diameter versus Percent Mass for BIS Simulant, Trial 1

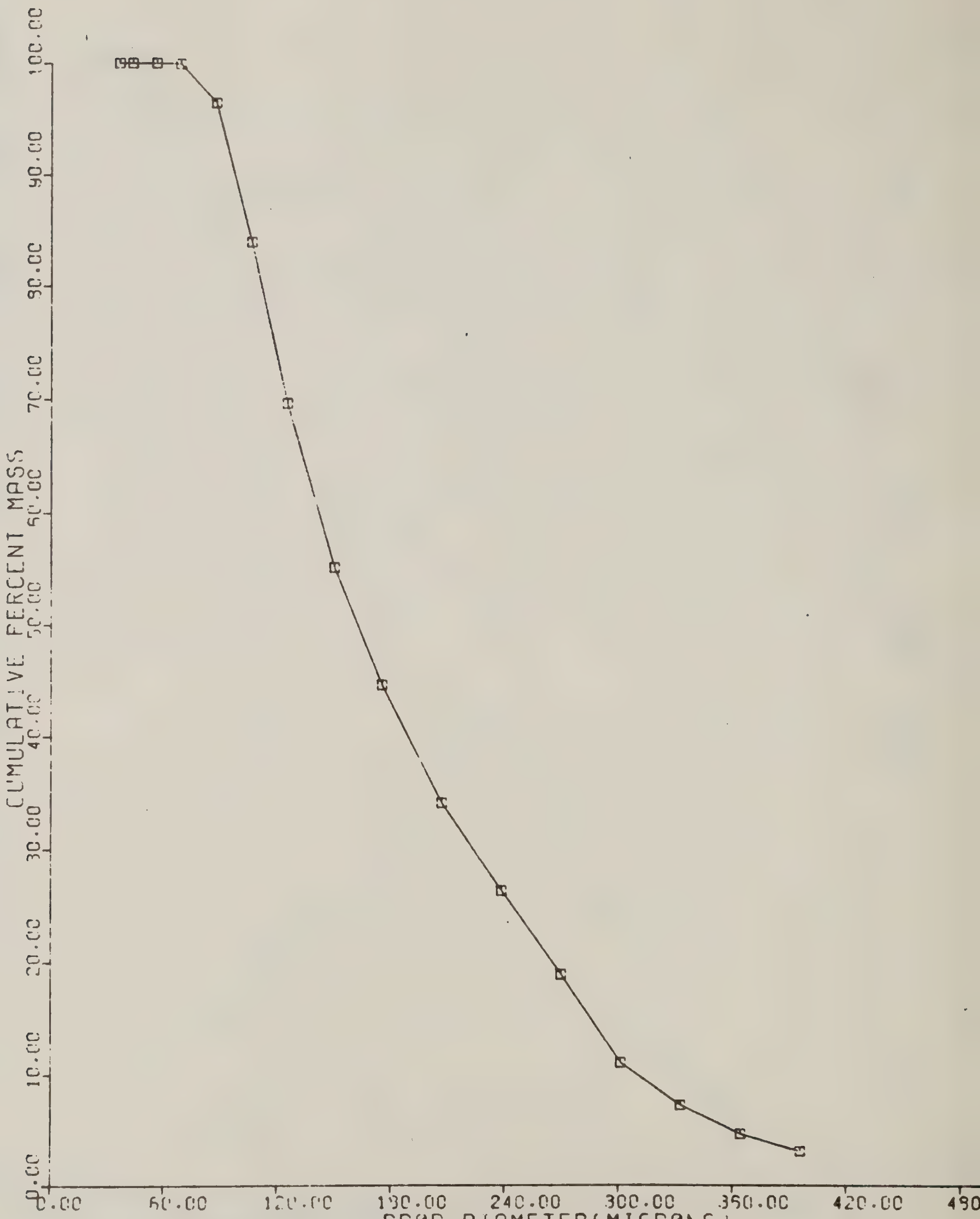


Figure 11. Drop Diameter versus Cumulative Percent Mass for BIS Simulant, Trial 3

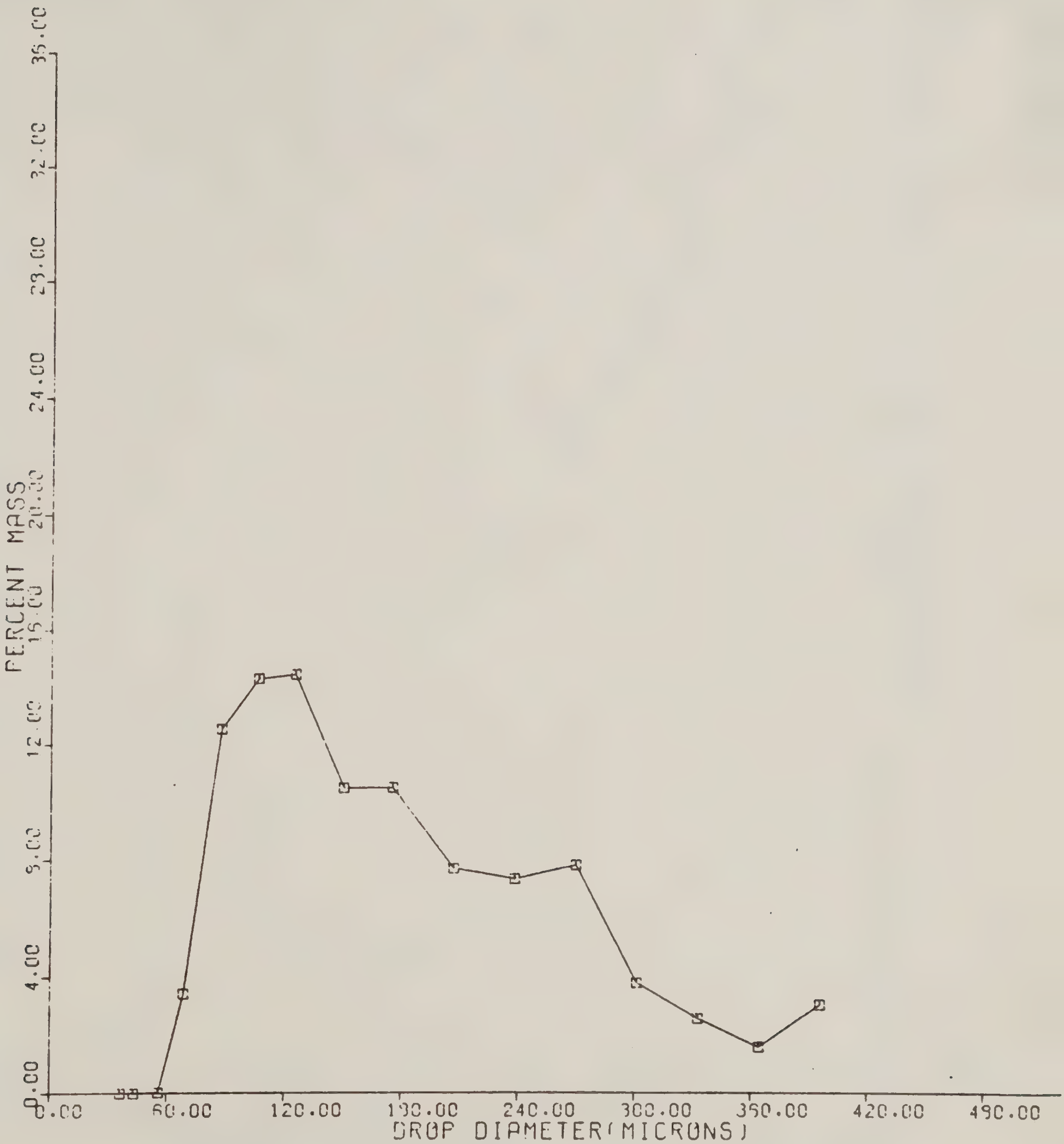


Figure 12. (U) Drop Diameter versus Percent Mass for BIS Simulant Trial 3 (U)

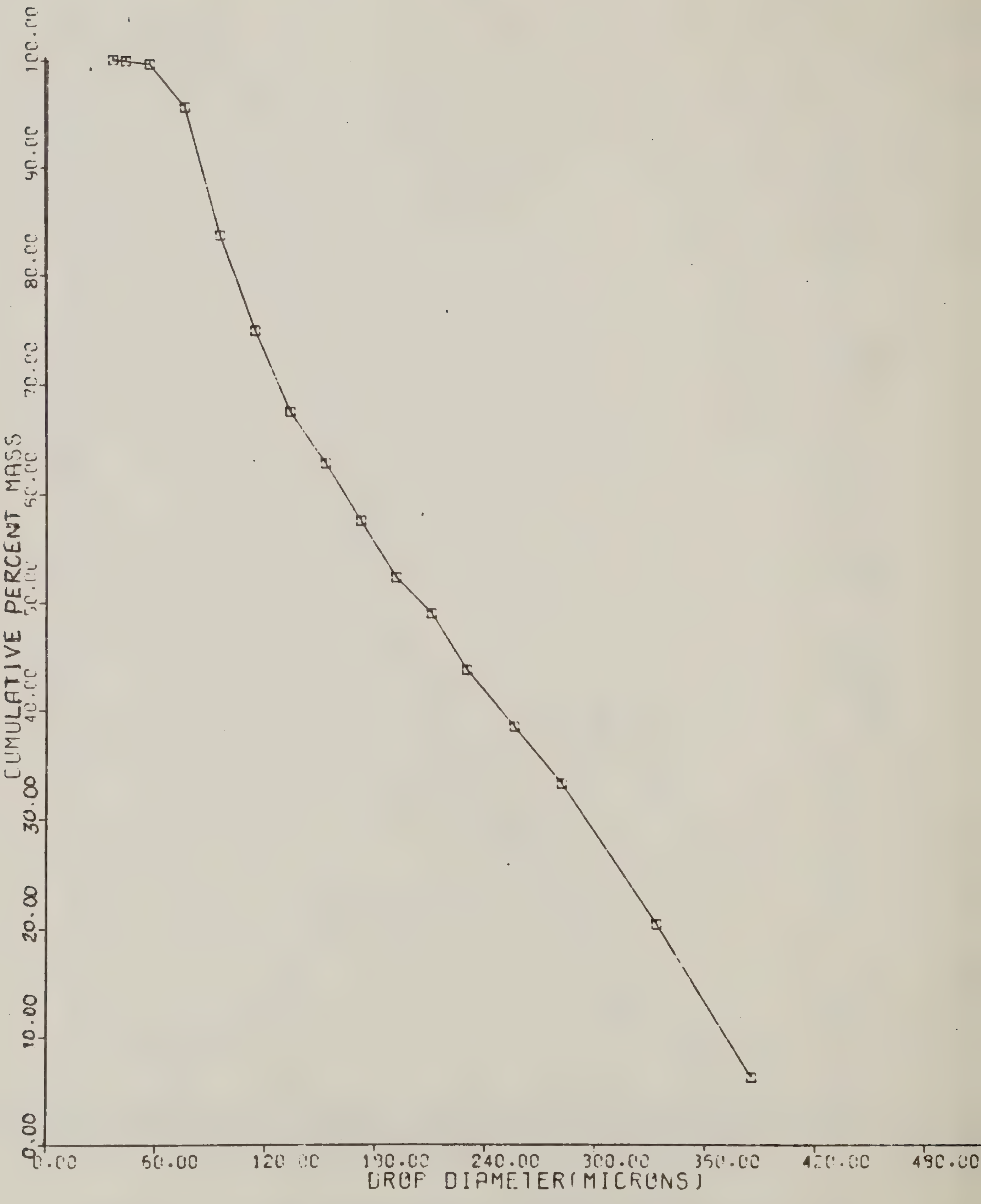


Figure 13. Drop Diameter versus Cumulative Percent Mass for TOP Simulant, Trial 2

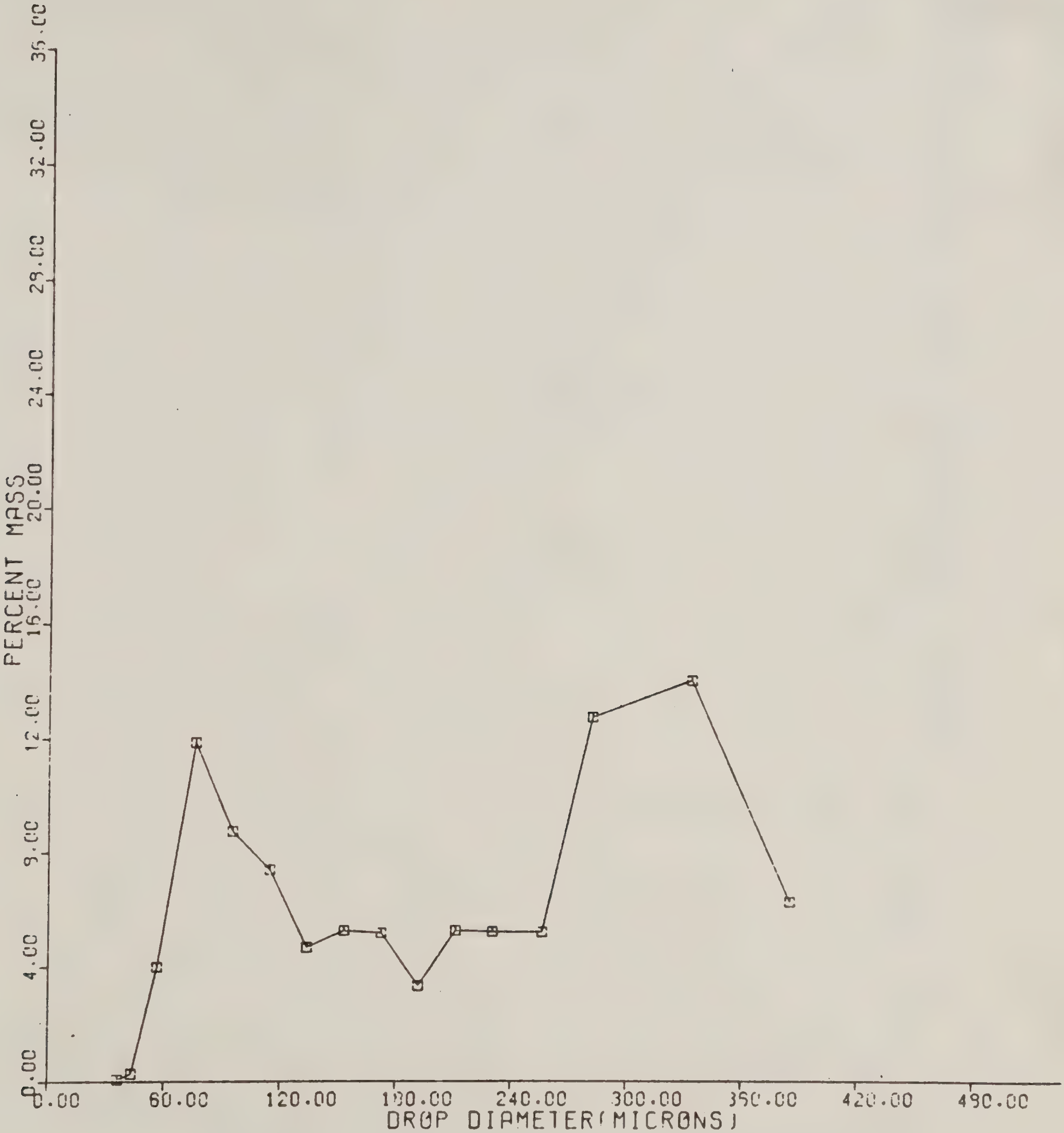


Figure 14. Drop Diameter versus Percent Mass for TOF Simulant Trial 2

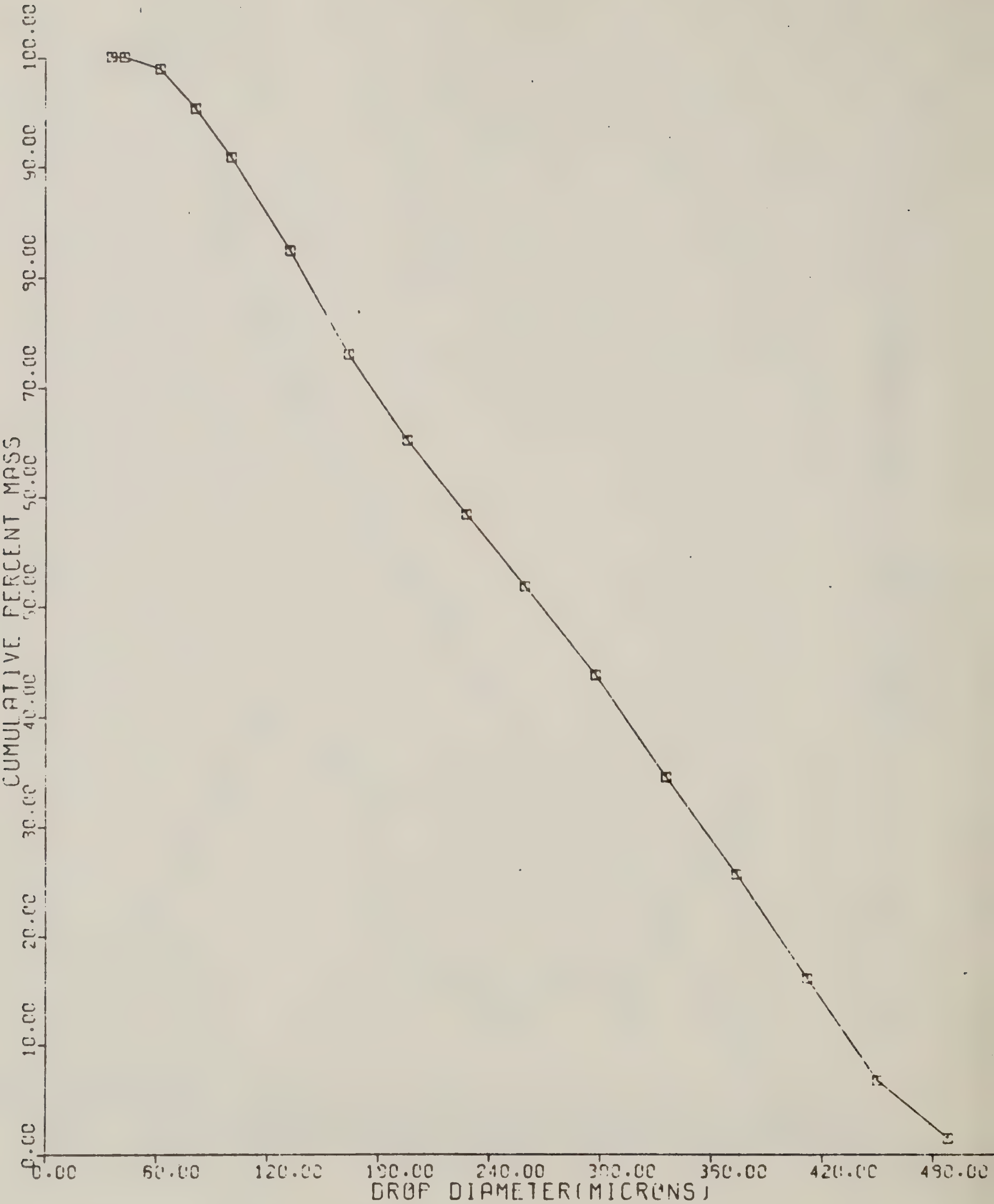


Figure 15. Drop Diameter versus Cumulative Percent Mass for TOF Simulant, Trial 4

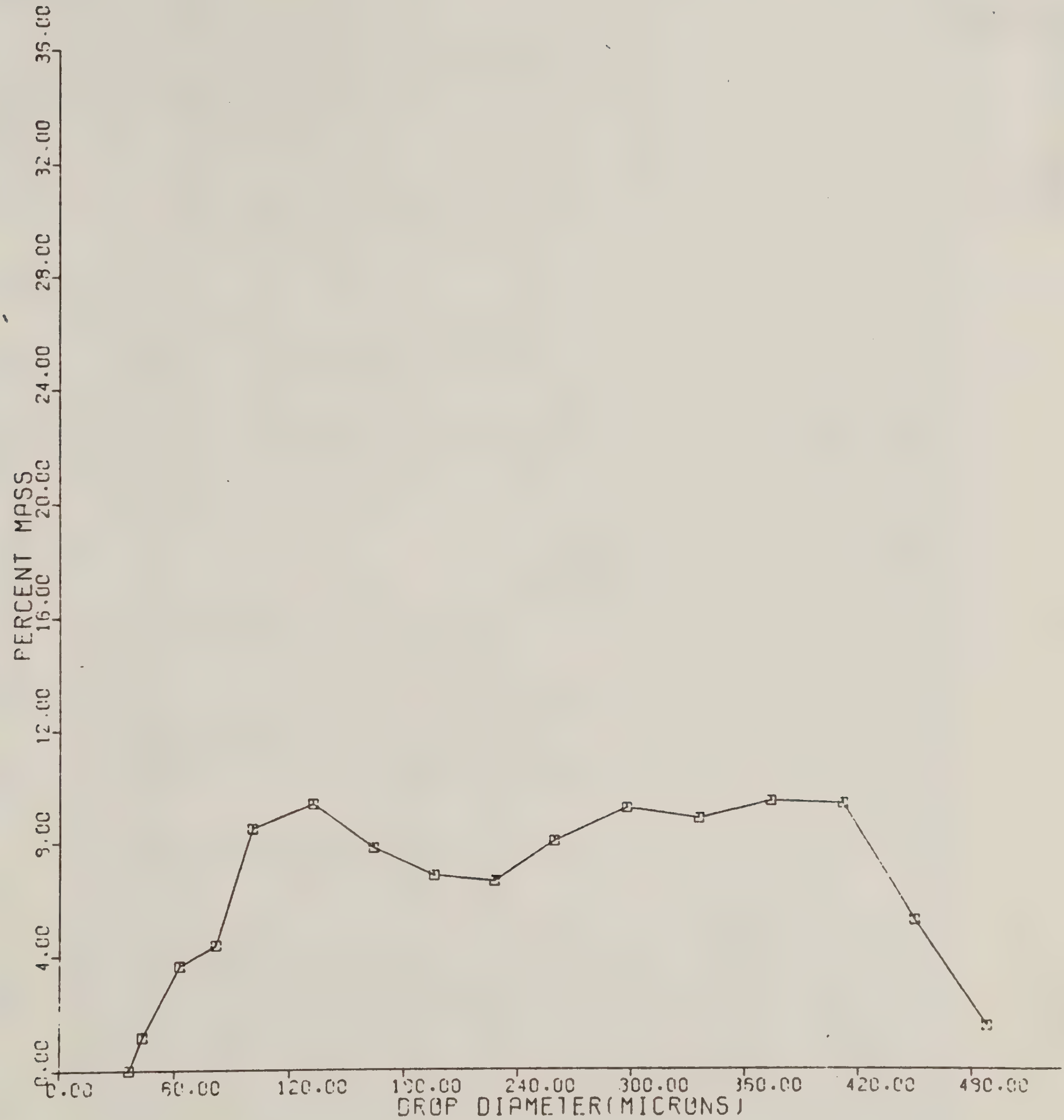


Figure 16. Drop Diameter versus Percent Mass for TOF Simulant Trial 4

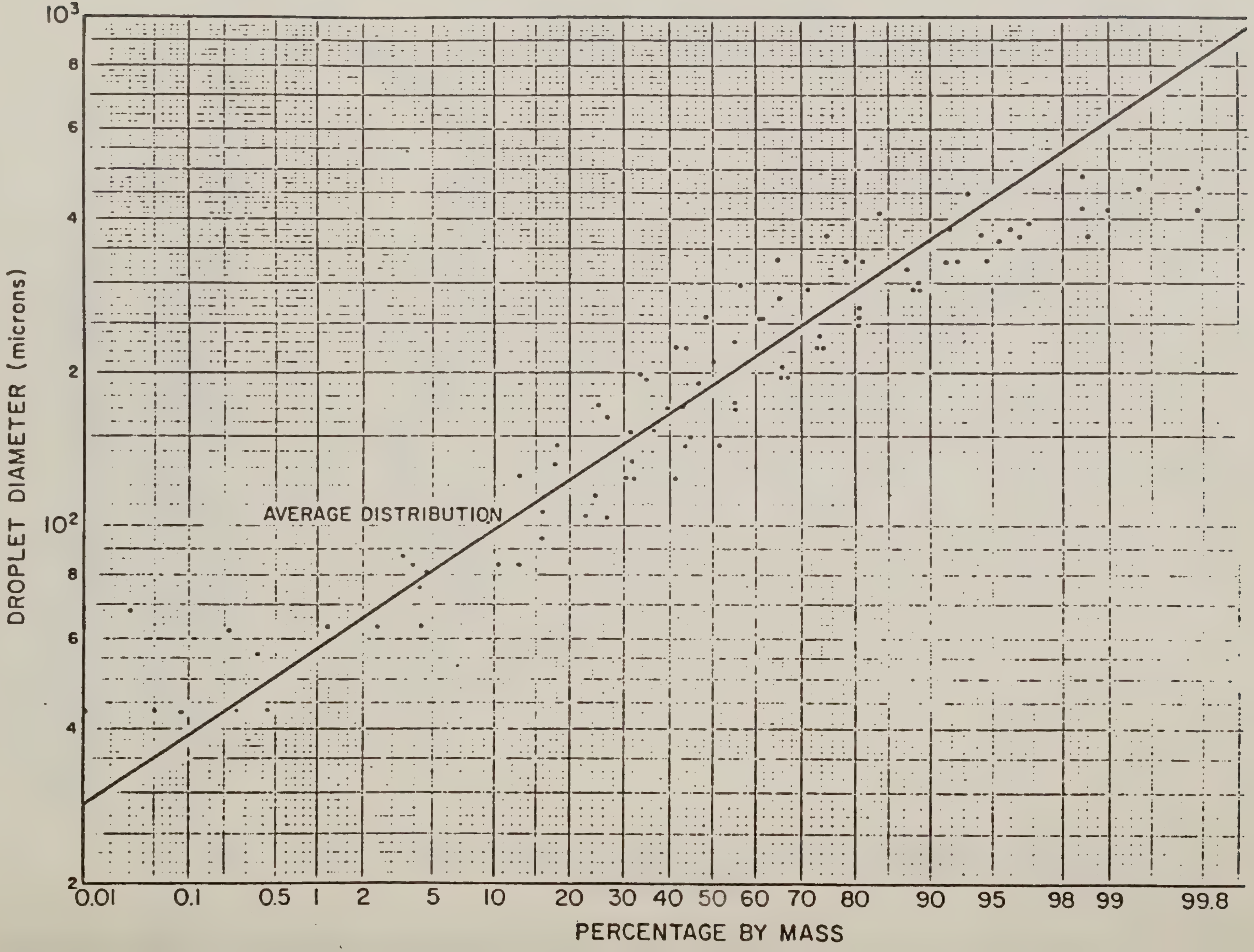


Figure 21. (U) Average Droplet Size Distribution for Trials 1 Through 5 (U)

Table A-8. Summary of Droplet Data (ASCAS) for 70-11 Subtest 3, Trial 1

ASCAS[a] Setting by Size		Diameter Equivalencies (microns)				Average Drop	Accountable		Percent Mass	
Category Number	Film Image (microns) (Lower Limit)	Lower Limit		Category Average		Mass (g)[e]	Drops[f]	Mass		
		Stain[b]	Drop[c]	Stain[d]	Drop	$x10^{-8}$	$(x10^5)$	(g)	[g]	Cumulations
1	0	0.0	36.1	32.0	39.8	3.1	0	0	0	100.00
2	11	61.0	43.2	87.1	46.2	4.8	0	0	0	100.00
3	21	116.4	49.6	142.1	52.6	7.1	12.2	86	0.04	100.00
4	31	171.9	56.1	197.4	59.0	10.0	17.3	173	0.09	99.96
5	41	227.3	62.5	281.7	68.8	15.9	66.0	1049	0.53	99.87
6	61	338.2	75.4	392.1	81.7	26.5	257.8	6839	3.47	99.34
7	81	449.1	88.3	502.7	94.5	41.1	188.0	7731	3.92	95.87
8	101	560.0	101.2	613.5	107.4	60.3	158.1	9533	4.83	91.95
9	121	670.9	114.1	752.8	123.6	91.9	187.2	17205	8.72	87.12
10	151	837.3	133.4	918.9	142.9	142.0	140.2	19916	10.09	78.41
11	181	1003.0	152.7	1085.0	162.2	207.8	102.7	21334	10.81	68.31
12	211	1170.0	172.1	1336.9	191.5	341.8	90.0	30743	15.58	57.50
13	271	1502.7	210.7	1726.4	236.7	645.9	53.4	34495	17.48	41.93
14	351	1946.3	262.3	2197.7	291.5	1206.0	19.0	22955	11.63	24.45
15	441	2445.3	320.3	2724.4	352.7	2136.0	8.2	17428	8.83	12.82
16	541	2999.8	384.7	3306.6	420.3	3617.0	2.2	7868	3.99	3.99
						Total	1302.1	197356	100.00	

MMD (m) 191

[a] Automatic Spot Counter and Sizer

[b] Product of film image setting and Photo Reduction Factor

PRF Trial 1 - 5.545 Trial 5 - 5.786
Trial 2 - 5.550 Trial 6 - 5.786
Trial 3 - 5.417 Trial 7 - 5.786
Trial 4 - 5.468

[c] Based on Equation: Drop Diameter = 36.11 + 0.1162 (Stain Diameter)

[d] Based on Equation: Category Average = $\{(U^3 - L^3) \div 3(U-L)\}^{\frac{1}{2}}$
U - Upper limit
L - Lower limit

[e] Based on Equation: Drop Mass (g) = $\pi/6$ (Drop Diameter)^3 (Agent Density)

[f] Accountable Number of Drops -

$$\sum_{1}^{n} (10{,}000\ cm^2 \div \{(1\ cm)(5.545)\}^2)(\text{Area of Assignment } m^2 \text{ of the affiliated grid position})$$

[g] As percent of total accountable mass

Table 6 Summary of Meteorology Data for 70-11, Phase I, Subtest 3

Trial No.	Date	Time	2-Meter Wind Speed and Direction		8-Meter Wind Speed and Direction		16-Meter Wind Speed and Direction		32-Meter Wind Speed and Direction		Mean Wind Speed[a] (m/sec)	Air Temperature (^oF)	Relative Humidity (%)	Temperature Gradient (0.5 to 4.0 m) (C^o)
			m/sec	(°)	m/sec	(°)	m/sec	(°)	m/sec	(°)				
1	7 Jun 72	0707:43 MDT	4.7	164	6.5	161	7.4	162	8.7	156	8.7	62.0	60	+ 0.3
2	27 Jul 72	0849:20 MDT	2.0	147	2.5	141	2.6	145	2.7	137	3.0	75.0	30	- 1.5
3	17 Aug 72	0738:43 MDT	4.1	162	ND[b]	ND	7.1	160	8.7	156	9.8	66.0	23	0.0
4	22 Sep 72	0910:44 MDT	ND	ND	ND	ND	ND	ND	ND	ND	8.0[c]	62.0	37	+ 1.0
5	30 Nov 72	1211:46 MST	6.8	159	ND	158	6.1	162	9.0	163	8.0[d]	43.5	50	0.0
6	31 Oct 73	1010:38 MST	ND	ND	ND	ND	ND	ND	ND	ND	4.0	55.9	29	-0.8
7	30 Nov 73	1432:30 MST	ND	ND	ND	ND	ND	ND	ND	ND	4.5	56.5	52	ND
8														

[a]Mean wind speed is from ground to release height and was estimated using droplet vectors, PIBAL data, and profile data from Tower 12.

[b]ND denotes no data.

[c]Met Tower 12 inoperative, wind direction 160 to 175^0

[d]PIBAL data.

Table A-9. Summary of Droplet Data (ASCAS) for 70-11, Subtest 3, Trial 2

ASCAS[a] Setting by Size		Diameter Equivalencies (microns)				Average Drop	Accountable		Percent Mass[g]	
Category Number	Film Image (microns) (Lower Limit)	Lower Limit		Category Average		Mass (g)[e] $\times 10^{-8}$	Drops[f] ($\times 10^5$)	Mass (g)		
		Stain[b]	Drop[c]	Stain[d]	Drop				%	Cumulations
1	0	0.0	36.1	32.0	39.8	3.0	87.4	266	0.09	100.00
2	11	61.0	43.2	117.8	49.8	6.0	147.3	877	0.29	99.91
3	31	172.0	56.1	256.8	65.9	13.8	881.9	12197	4.00	99.62
4	61	338.5	75.4	421.6	851.1	29.7	1219.4	36238	11.90	95.62
5	91	505.0	94.8	587.4	104.4	54.8	486.8	26683	8.76	83.72
6	121	671.5	114.1	753.5	123.7	91.2	247.9	22611	7.42	74.96
7	151	838.0	133.5	919.7	143.0	141.0	101.4	14294	4.69	67.54
8	181	1004.5	152.8	1086.0	162.3	206.2	78.1	16097	5.28	62.85
9	211	1171.0	172.2	1252.4	181.6	289.0	54.8	15846	5.20	57.57
10	241	1337.5	191.5	1418.4	201.0	391.4	26.1	10201	3.35	52.36
11	271	1504.0	210.8	1585.2	220.3	515.7	31.3	16125	5.29	49.01
12	301	1670.5	230.2	1779.9	242.9	691.4	23.1	15989	5.25	43.72
13	301	1670.5	230.2	2001.7	268.7	935.7	17.0	15950	5.24	38.47
14	381	2114.5	281.8	2337.2	307.7	1405.0	27.8	39048	12.82	33.24
15	461	2558.5	333.4	2780.7	359.2	2235.0	19.2	42960	14.10	20.42
16	541	3-02.5	385.0	3224.3	410.8	3342.0	5.8	19234	6.31	6.31
						Total	3455.3	304616	100.00	

MMD (m) 205

Table A-10. Summary of Droplet Data (ASCAS) for 70-11, Subtest 3, Trial 3

ASCAS[a] Setting by Size		Diameter Equivalencies (microns)				Average Drop	Accountable		Percent Mass	
Category Number	Film Image (microns) (Lower Limit)	Lower Limit		Category Average		Mass (g)[e] $\times 10^{-8}$	Drops[f] ($\times 10^5$)	Mass (g)		Cumulations
		Stain[b]	Drop[c]	Stain[d]	Drop					
1	0	0.0	36.1	31.3	39.7	3.0	0	0	0	100.00
2	11	59.6	43.0	115.0	49.5	5.8	0	0	0	100.00
3	31	167.9	55.6	221.4	61.8	11.4	6.4	73	0.03	100.00
4	51	276.3	68.2	357.7	77.7	22.6	340.0	7685	3.43	99.97
5	81	438.8	87.1	519.3	96.5	43.3	649.6	28109	12.56	96.54
6	111	601.3	106.0	681.3	115.3	73.9	434.6	32113	14.34	83.98
7	141	763.8	124.9	871.6	137.4	125.0	259.4	32443	14.49	69.64
8	181	980.5	150.0	1087.8	162.5	207.0	113.9	23573	10.53	55.14
9	221	1197.2	175.2	1332.1	190.9	335.5	70.3	23592	10.54	44.61
10	271	1468.0	206.7	1602.6	222.3	530.0	32.7	17335	7.74	34.08
11	321	1738.9	238.2	1873.1	253.8	788.1	21.0	16527	7.38	26.33
12	371	2009.7	269.6	2143.8	285.2	1119.0	15.7	17599	7.86	18.95
13	421	2280.6	301.1	2414.5	316.7	1531.0	5.6	8553	3.82	11.09
14	471	2551.4	332.6	2685.2	348.1	2035.0	2.8	5798	2.59	7.27
15	54	2822.3	364.1	2956.0	379.6	2638.0	1.4	3608	1.61	4.68
16	571	3093.1	395.5	3226.7	411.1	3349.0	2.1	6871	3.07	3.07
						Total	1955.6	223878	100.00	

MMD (m) 162

Table A-11 Summary of Droplet Data (ASCAS) for 70-11 Subtest 3, Trial 4

ASCAS[a] Setting by Size		Diameter Equivalencies (microns)				Average Drop	Accountable		Percent Mass	
Category Number	Film Image (microns) (Lower Limit)	Lower Limit		Category Average		Mass (g)[e] $\times 10^{-8}$	Drops[f] ($\times 10^{5}$)	Mass (g)	[g]	Cumulations
		Stain[b]	Drop[c]	Stain[d]	Drop					
1	0	0.0	31.6	31.6	39.8	3.0	16.8	51	0.01	100.00
2	11	60.1	43.1	146.8	53.2	7.2	592.7	4295	1.16	99.99
3	41	224.2	62.2	306.9	71.8	17.8	759.5	13541	3.64	98.83
4	71	388.2	81.2	459.7	90.7	36.0	451.8	16254	4.37	95.19
5	101	552.7	100.3	690.6	116.4	76.0	415.3	31545	8.49	90.82
6	151	825.7	132.1	962.7	148.0	156.3	223.2	34878	9.38	82.33
7	201	1099.1	163.8	1235.5	179.7	279.7	103.8	29026	7.81	72.95
8	251	1372.5	195.6	1508.4	211.4	455.5	55.7	25349	6.82	65.14
9	301	1645.9	227.4	1781.5	243.1	693.0	35.5	24573	6.61	58.32
10	351	1919.3	259.1	2082.7	278.1	1037.0	28.9	29938	8.05	51.71
11	411	2247.3	297.3	2410.5	316.2	1525.0	22.5	34280	9.22	43.65
12	471	2575.4	335.4	2738.3	354.3	2145.0	15.3	32868	8.84	34.43
13	531	2903.4	335.4	3066.2	392.4	2914.0	12.1	35202	9.47	25.59
14	591	3231.6	411.6	3394.2	430.5	3848.0	9.1	34864	9.38	16.12
15	651	3559.7	449.7	3722.1	468.6	4963.0	3.9	19430	5.23	6.74
16	711	3887.7	487.9	4050.1	506.7	6295.0	0.9	5615	1.51	1.51
						Total	2746.8	371708	100.00	

MMD (m) 267

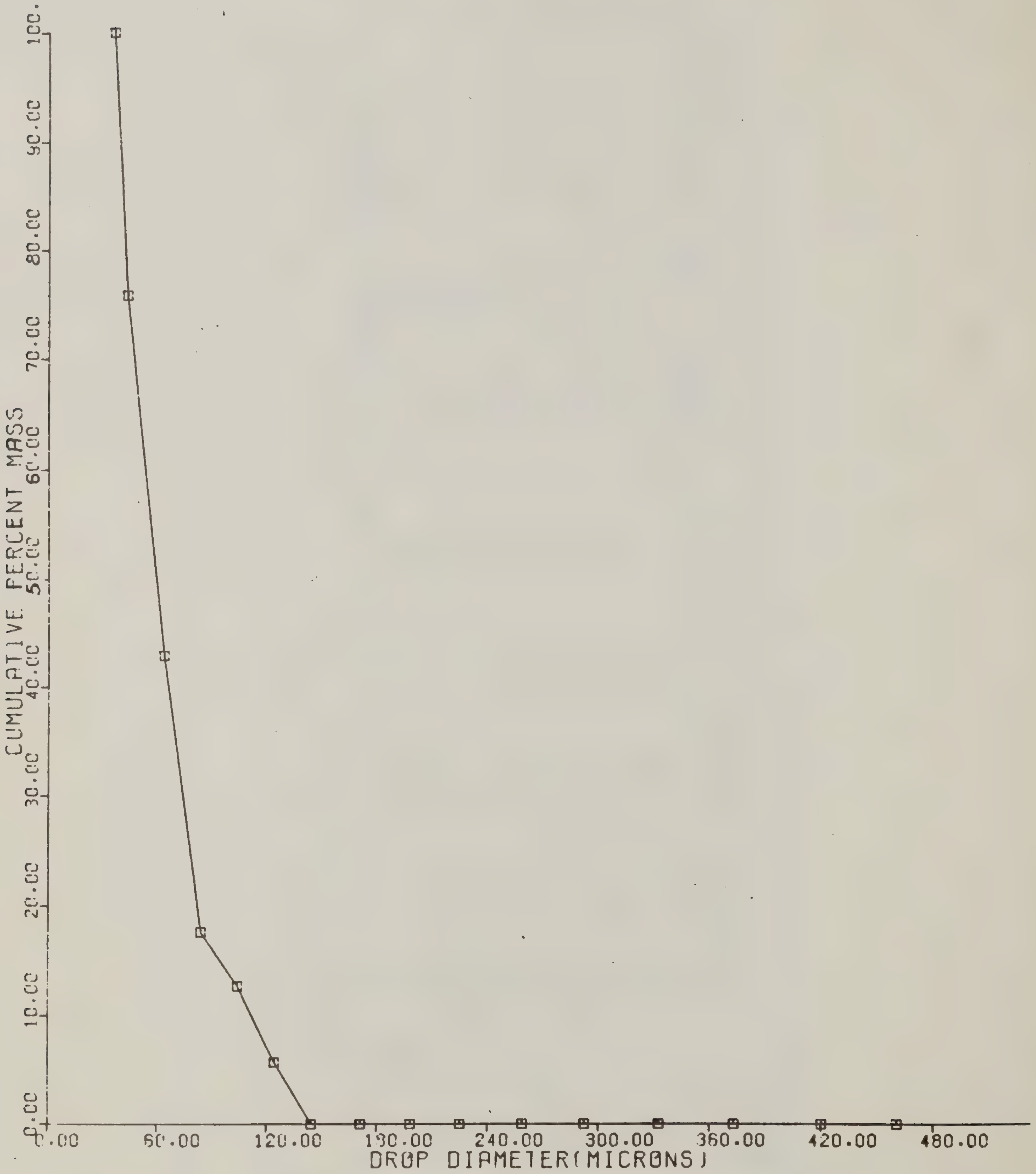


Figure A-8. Drop Diameter Versus Cumulative Percent Mass for BIS Simulant, DPG Test 70-11 I, Trial 5

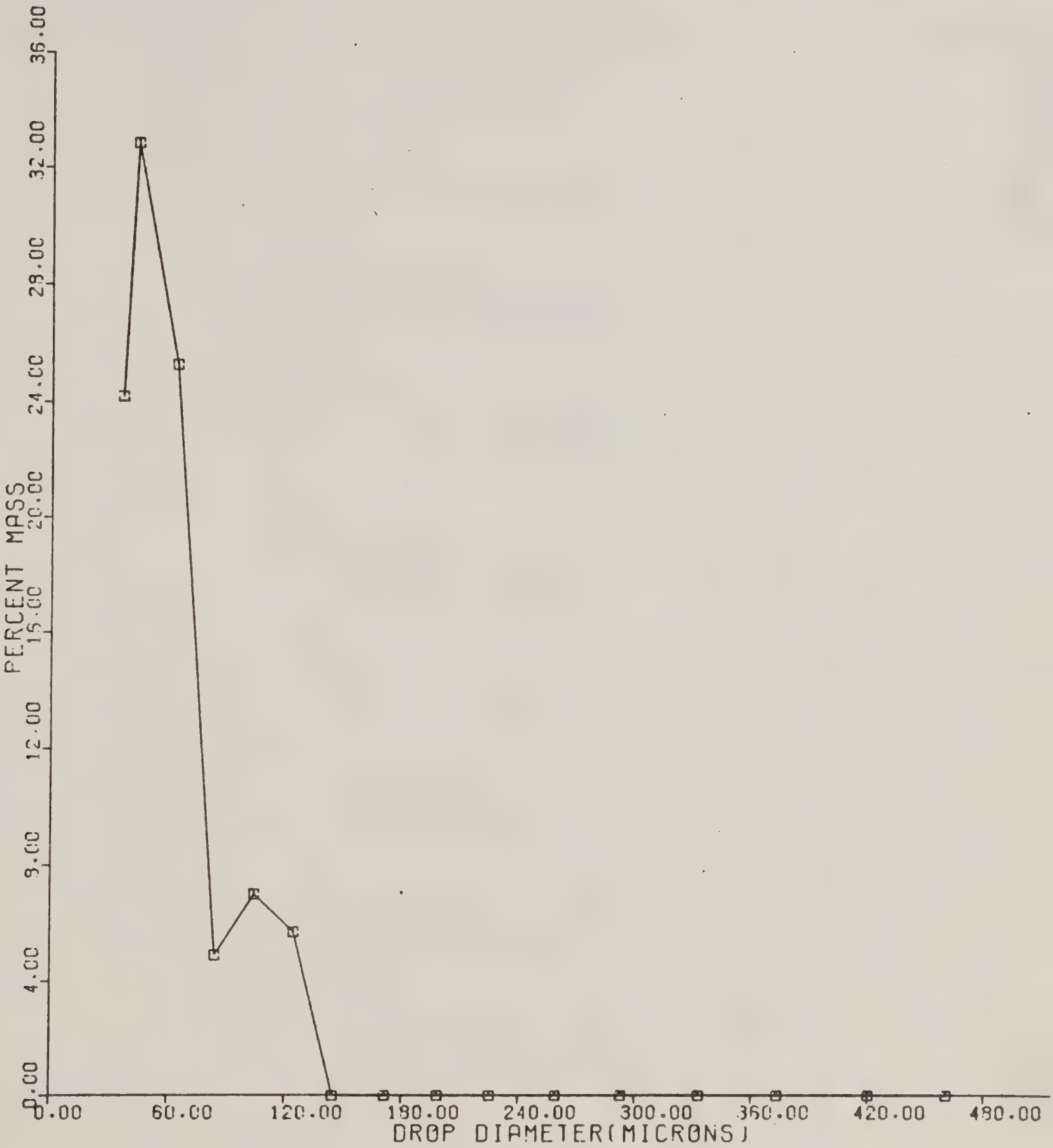


Figure A-9. Drop Diameter Versus Percent Mass for BIS Simulant, DPG Test 70-11 I, Trial 5

Table A-12. Summary of Droplet Data (ASCAS) for 70-11 Subtest 3, Trial 5.

ASCAS[a] Setting by Size		Diameter Equivalencies (microns)				Average Drop	Accountable		Percent Mass	
Category Number	Film Image (microns) (Lower Limit)	Lower Limit Stain[b]	Lower Limit Drop[c]	Category Average Stain[d]	Category Average Drop	Mass (g)[e] $X10^{-8}$	Drops[f] (x105)	Mass (g)	g	Cumulations
1	0	0.0	36.1	33.4	40.0	3.1	76.9	239	.05	100.00
2	11	63.6	43.5	155.3	54.2	7.7	682.1	5276	1.14	99.95
3	41	237.2	63.7	324.8	73.8	19.6	648.2	12710	2.76	98.80
4	71	410.8	83.8	497.1	93.9	40.3	521.4	21001	4.55	96.05
5	101	584.4	104.0	670.0	114.0	72.1	285.5	20578	4.46	91.50
6	131	785.0	124.2	843.3	134.1	117.4	193.2	22682	4.92	87.03
7	161	931.5	144.4	1046.4	157.7	191.0	169.9	32448	7.03	82.12
8	201	1163.0	171.2	1277.5	184.6	306.1	136.1	41665	9.03	75.08
9	241	1394.4	189.1	1508.7	211.4	460.1	99.2	45626	9.89	66.05
10	281	1625.9	225.0	1769.5	241.7	687.8	115.8	79638	17.27	56.16
11	331	1915.2	258.7	2058.5	275.3	1016.0	47.5	48221	10.45	38.89
12	381	2204.5	292.3	2377.2	312.3	1484.0	30.4	45062	9.77	28.44
13	441	2551.6	332.6	2724.1	352.6	2136.0	27.9	59524	12.90	18.67
14	501	2898.8	372.9	3100.5	396.4	3033.0	6.5	19695	4.27	5.77
15	571	3303.8	420.0	3475.9	440.0	4148.0	1.0	4144	0.90	1.50
16	631	3651.0	460.4	3852.3	483.7	5512.0	0.5	2753	0.60	0.60
						TOTAL	3041.9	461262	100.00	

MMD (m) -237

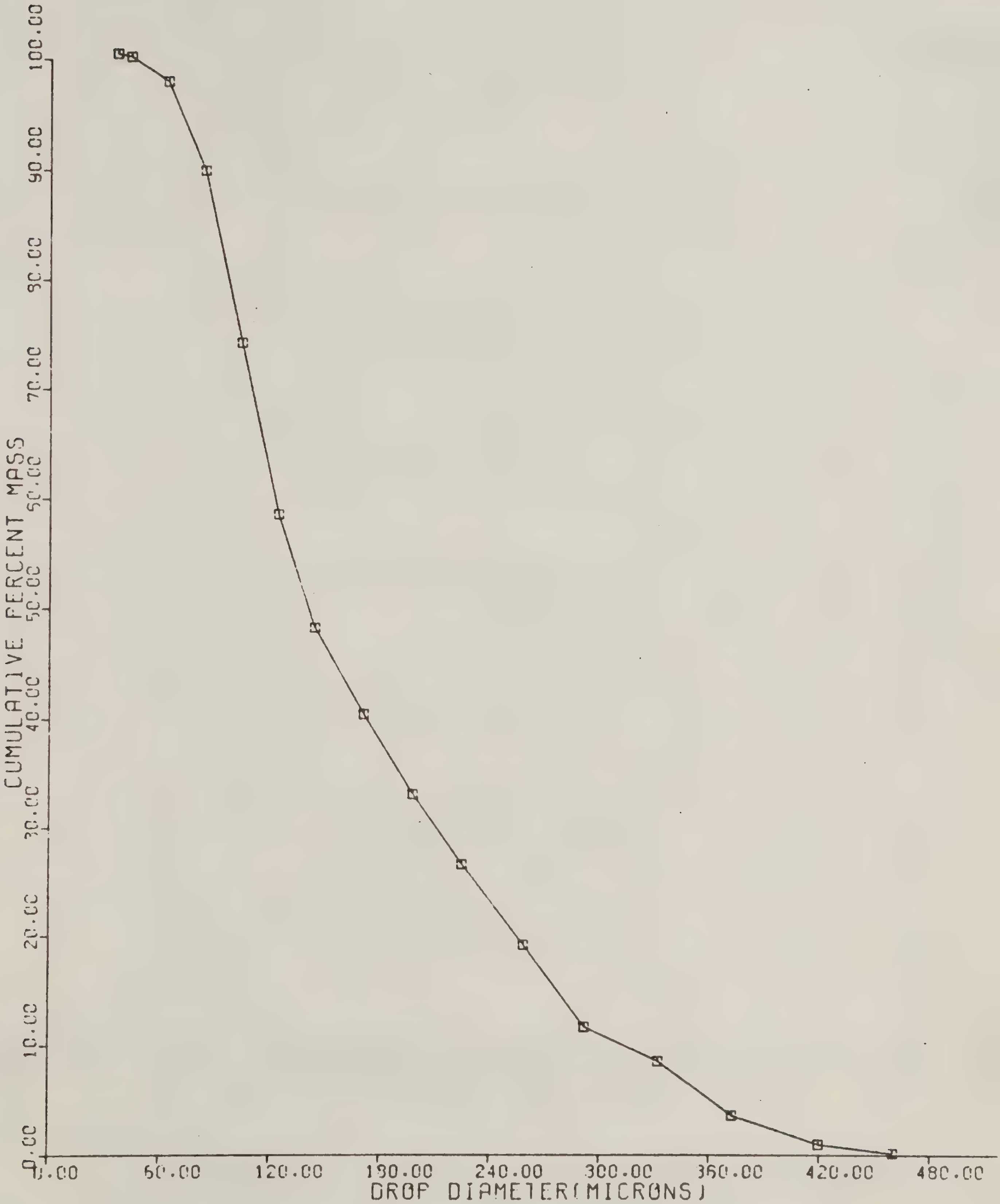


Figure A-10. Drop Diameter Versus Cumulative Percent Mass for EIS Simulant, DPG Test 70-11 I, Trial 6

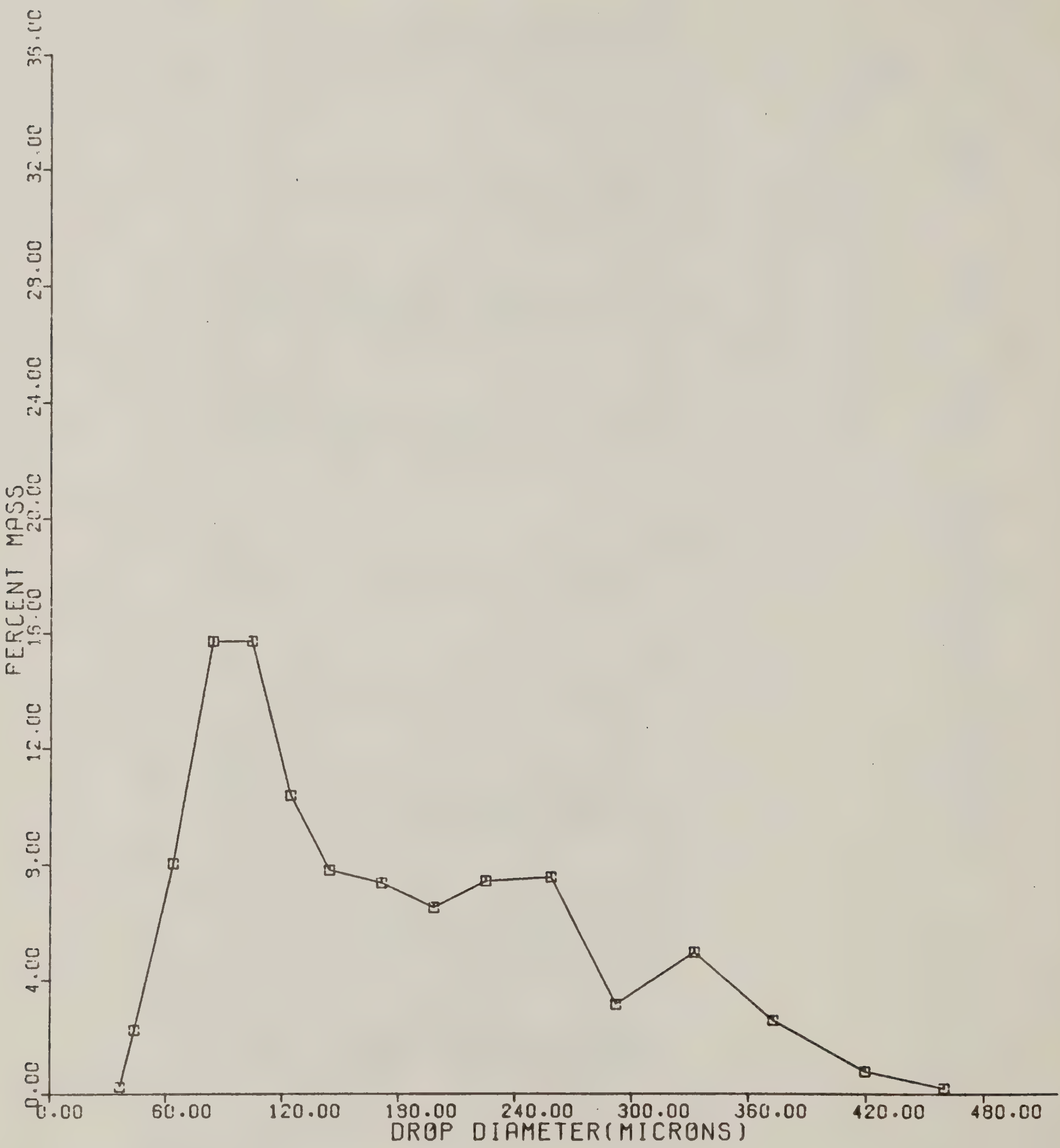


Figure A-11. Drop Diameter Versus Percent Mass for BIS Simulant, DPG Test 70-11 I, Trial 6

Table A-13. Summary of Droplet Data (ASCAS) for 70-11 Subtest 3, Trial 6.

ASCAS[a] Setting by Size		Diameter Equivalencies (microns)				Average Drop	Accountable		Percent Mass	
Category Number	Film Image (microns) (Lower Limit)	Lower Limit		Category Average		Mass (g)[e] $X10^{-8}$	Drops[f] $(x10^5)$	Mass (g)	g	Cumulations
		Stain[b]	Drop[c]	Stain[d]	Drop					
1	0	0.0	36.1	33.4	40.0	3.1	210.1	654	.25	100.00
2	11	63.6	43.5	155.3	54.1	7.7	751.8	5805	2.25	99.75
3	41	237.2	63.6	324.8	73.8	19.6	1056.8	20669	8.03	97.49
4	71	410.8	83.8	497.1	93.8	40.2	1007.6	40455	15.71	89.47
5	101	584.4	103.9	670.0	113.8	71.8	541.8	38914	15.11	73.76
6	131	758.0	124.0	843.3	133.9	117.0	228.0	26674	10.36	58.64
7	161	931.5	144.2	1046.4	157.5	190.2	105.5	20068	7.79	48.29
8	201	1163.0	171.0	1277.5	184.3	304.8	62.1	18926	7.35	40.49
9	241	1394.4	197.9	1508.7	211.1	458.2	36.6	16753	6.51	33.4
10	281	1625.9	244.7	1769.5	241.4	684.8	27.9	19087	7.41	26.64
11	331	1915.2	258.3	2058.6	274.9	1012.0	19.2	19404	7.54	19.22
12	381	2204.5	291.8	2377.2	311.9	1477.0	5.5	8116	3.15	11.69
13	441	2551.6	332.1	2724.1	252.1	2126.0	6.0	12742	4.95	8.54
14	501	2898.8	372.4	3100.5	395.8	3019.0	2.2	6635	2.58	3.59
15	571	3303.8	419.4	3475.9	439.3	4129.0	0.5	2062	0.80	1.01
16	631	3651.0	459.6	3852.3	483.0	5486.0	0.1	548	0.21	0.21
						TOTAL	4061.7	257512	100.00	

MMD (m) 141

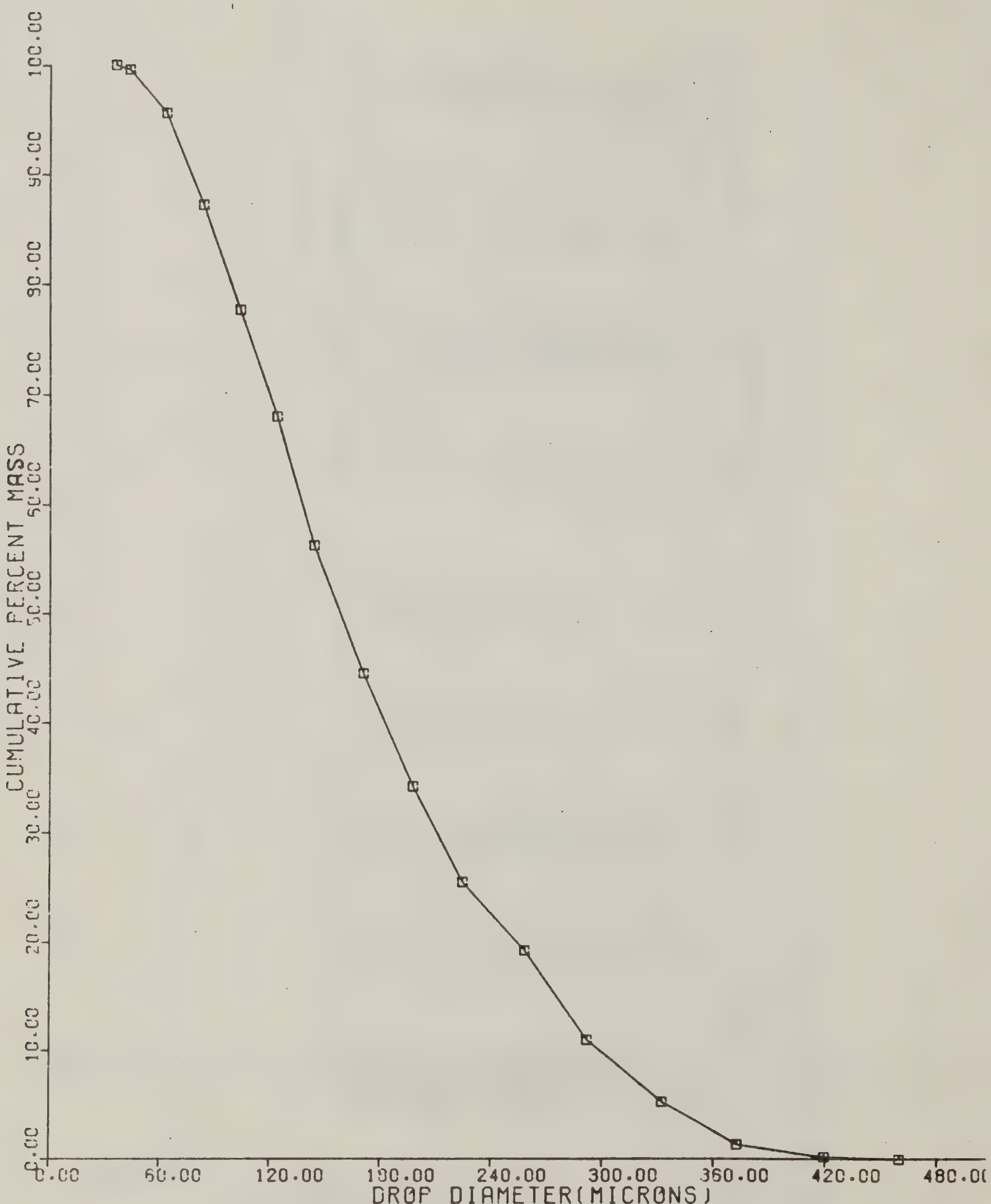


Figure A-12. Drop Diameter Versus Cumulative Percent Mass for BIS Simulant, DPG Test 70-11 I, Trial 7

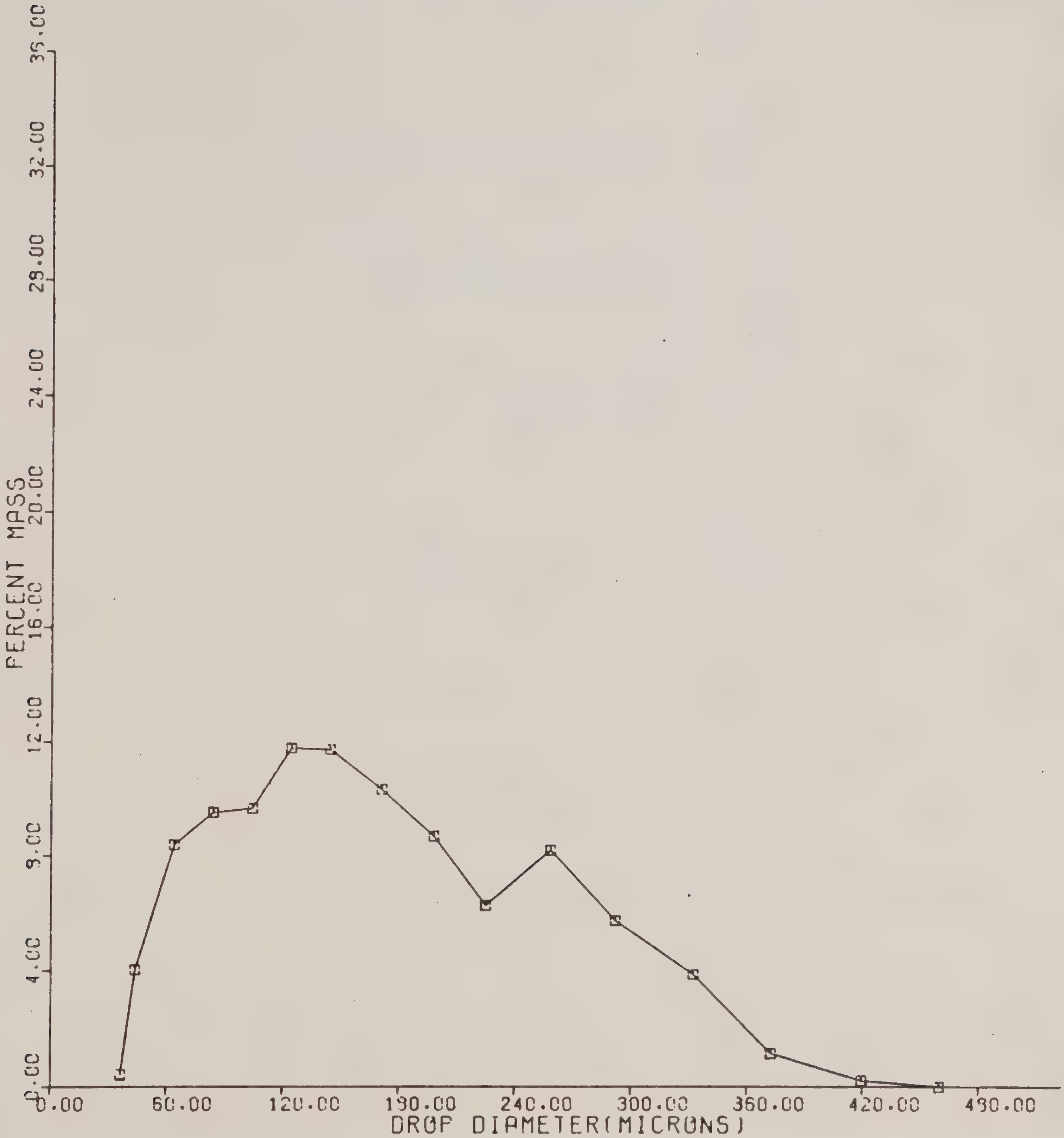


Figure A-13. Drop Diameter Versus Percent Mass for BIS Simulant, DPG Test 70-11 I, Trial 7

Table A-14. Summary of Droplet Data (ASCAS) for 70-11 Subtest 3, Trial 7.

ASCAS[a] Setting by Size		Diameter Equivalencies (microns)				Average Drop	Accountable		Percent Mass	
Category Number	Film Image (microns) (Lower Limit)	Lower Limit Stain[b]	Lower Limit Drop[c]	Category Average Stain[d]	Category Average Drop	Mass (g)[e] $X10^{-8}$	Drops[f] (x105)	Mass (g)	g	Cumulations
1	0	0.0	36.1	33.4	40.0	3.1	1071.7	3336	.42	100.00
2	11	63.6	43.5	155.3	54.1	7.7	4116.7	31783	4.04	99.58
3	41	273.2	63.6	324.8	73.8	19.6	3369.9	65909	8.38	95.53
4	71	410.8	83.8	497.1	93.8	40.2	1864.9	74874	9.52	87.15
5	101	584.4	103.9	670.0	113.8	71.8	1057.1	75932	9.66	77.63
6	131	758.0	124.0	843.3	133.9	117.0	791.6	92595	11.78	67.97
7	161	931.5	144.2	1046.4	157.5	190.2	484.9	92243	11.73	56.20
8	201	1163.0	171.0	1277.5	184.3	304.8	266.3	81160	10.32	44.46
9	241	1394.4	197.9	1508.7	211.1	458.2	149.2	68360	8.69	34.14
10	281	1625.9	224.7	1769.5	241.4	684.8	71.8	49188	6.26	25.45
11	331	1915.2	258.3	2058.6	274.9	1012.0	63.7	64478	8.20	19.19
12	381	2204.5	291.8	2377.2	311.9	1477.0	30.6	45152	5.74	10.99
13	441	2551.6	332.1	2724.1	352.1	2126.0	14.4	30580	3.89	5.25
14	501	2898.8	372.4	3100.5	395.8	3019.0	3.0	9047	1.15	1.36
15	571	3303.8	419.4	3475.9	439.3	4129.0	0.4	1650	0.21	0.21
16	631	3651.0	459.6	3852.3	483.0	54860	0.0	0	0.00	0.00
						TOTAL			100.00	

MMD (m) 158

APPENDIX

II

TR-76-303-02

COMPARISON OF CALCULATED AND OBSERVED DOSAGE AND DEPOSITION FOR SUBTEST 3, 70-11 TEST SERIES

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SECTION 1
INTRODUCTION

1.1 BACKGROUND

Phase I, Subtest 3 of the 70-11 Test Series was conducted at Dugway Proving Ground (DPG) in the latter half of 1972 and during 1973 to provide data for the operational evaluation of a modified spray tank system mounted on a high performance jet aircraft and for the development of sampling and assessment technology for the deposition and downwind drift of chemical aerosol droplets less than 100 micrometers in diameter. In these tests, which were conducted at the Target S-Downwind Grid complex, a liquid simulant tagged with fluorescent particles (FP) and dyes was emitted from the aircraft spray system along a flight line normal to the wind. Measurements of droplet deposition and dosages of spray droplets were made by means of a sampling network extending a maximum distance of 15 miles downwind from the flight line.

The second objective of the 70-11 Test Series, the development of sampling and assessment technology for chemical aerosol droplets less than 100 micrometers in diameter, was of major interest to DPG. The primary method employed at DPG and elsewhere for measuring spray deposition consists of mixing dye with the liquid to be sprayed, collecting the spray droplets on suitable cards placed on the ground surface, and counting and sizing the stains produced by the dye-marked droplets impacting on the cards. To facilitate the counting and sizing of stains, DPG had earlier developed the ASCAS (Automatic Spot Counter and Sizing) system. This system can accurately count and size droplets as small as 20 micrometers in diameter (stains 40 micrometers or larger) when the dye simulant mix is good and the cards are clean. However, the presence of dust on the cards and other factors may limit the accuracy of the ASCAS counts of drops less than 60 micrometers in diameter.

Colorimetric and gas-liquid chromatographic analysis procedures can be used to estimate the total mass of droplets deposited on filter paper; however, they cannot be used to differentiate between mass deposited by droplets of different sizes. Moreover, they cannot be used to measure mass contribution by small droplets when the mass sampled is below the lower sensitivity of the analytical method. Thus, in general at some distance downwind of the source, other methods must be used to determine mass deposition.

Murray, et al. (1970) suggested that sampling of FP (fluorescent particle) tagged droplets could be used to estimate ground level deposition and the downwind drift of droplets less than 100 micrometers in diameter. They hypothesized that the number of FP contained in individual droplets is a function of droplet size and suggested that FP counts on rotorod samples could be used to estimate deposition and dosage of small-diameter droplets. Following this suggestion, DPG conducted preliminary field studies during Subtest 2, Phase I of the 70-11 Test Series. These studies showed that the number of FP contained in droplets of various diameters is statistically predictable. Consequently, the FP-tagging and rotorod-sampling techniques were scheduled for evaluation during Subtest 3.

1.2 PURPOSE

Cramer, et al., (1972) describes atmospheric transport and diffusion models developed for use by DPG in estimating the deposition and air dosage downwind from volume and line source releases of droplets or particles with known settling velocities. Recent modifications of the models include a provision to account for the effects of partial reflection of small droplets and particles at the ground surface as a function of their settling velocity. The measurements made during Subtest 3 provided data for use in testing the performance of the updated models. The main purpose of the study described in this technical report was to compare

the model-predicted downwind drift of small droplets (deposition and dosage) with measurements from Subtest 3. A secondary purpose of the study was to evaluate the procedure suggested by Murray, *et al.*, (1970) for estimating ground deposition from dosage measurements of FP-tagged droplets using rotorod samplers.

1.3 ORGANIZATION OF THE REPORT

Section 2 describes the sampling grid and the procedures used to compute the observed deposition and dosage parameters for comparison with model predictions. A description of the deposition and dosage models is given in Section 3. Source and meteorological inputs used in the model calculations are given in Section 4. In Section 5, comparisons are presented of the observed and predicted deposition and dosage for Subtest 3 of the 70-11 Test Series. Section 5 also presents normalized deposition and dosage profiles that illustrate the relative effects of settling velocity, wind speed and other parameters on deposition and dosage profiles.

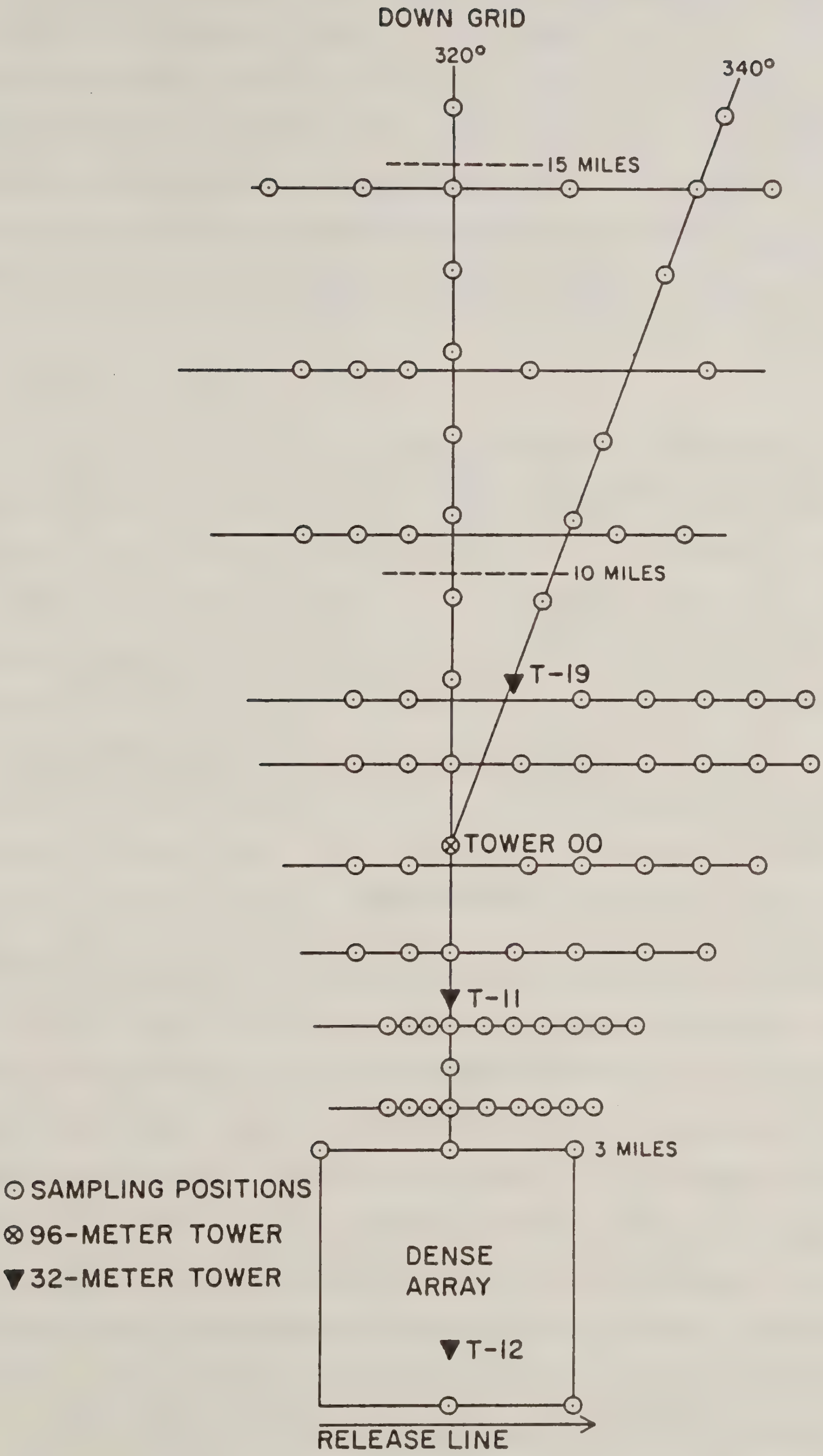

FIGURE 2-1. Downwind sampling grid array for Subtest 3, 70-11 Test Series.

the release rate from the aircraft spray tank was not uniform in many of the trials. Additionally, the length of the release line was difficult to determine because of the trail-off of material that occurred as the spray liquid in the tank was depleted. To minimize the effects of the uncertainties in the deposition data produced by the above factors, we selected the crosswind integrated deposition as the primary observed parameter. The crosswind integrated deposition for each row in the dense inner grid array was calculated from the deposition measurements by use of the expression

$$\mathrm{Dep(cwi)} = \sum_{i=1}^{n} \mathrm{Dep}_i \, \Delta s_i \tag{2-1}$$

where

Dep_i = deposition at the i^{th} sampler in a row with n samplers

Δs_i = Representative crosswind width assigned to the i^{th} sampler (182.88m)

Dosage Data

The number of rotorod positions for measuring air dosages was considerably less than the number of positions used for deposition measurements, and only a few rotorods were located within the first 5 kilometers downwind from the flight line. At each rotorod position, dosage measurements were made using a sampler equipped with an H shaped and a U shaped collecting rod. The H shaped rod is rotated at a higher speed and is more efficient in collecting drops with small diameters while the U shaped rod is more efficient for drops with large diameters. With the exception of Trial 5, air dosage measurements made on the downwind grid at distances beyond 5 kilometers were generally not usable because of wind shifts that caused the clouds to miss the sampling grid. For this reason, only air dosage measurements from Trial 5 could be used for comparison with model estimates.

To minimize the effects of the apparent variations in the release rate along the flight path and the small number of observations available at any given distance from the flight line, crosswind integrated dosage was selected as the primary air dosage parameter to be used in the model evaluation. The observed crosswind integrated air dosages for Trial 5 were calculated from an expression similar to Equation (2-1) with the air dosage measurements substituted for deposition measurements. Air dosages resulting from spray droplets less than 53 micrometers in diameter were determined from the number of FP collected on the H- and U-shaped rotorods at each sampling position.

As noted in Section 1.1, DPG established the relationship between the number of FP contained in a droplet and the droplet diameter prior to Subtest 3. A full explanation of the preparation of the FP simulant mix is given in the Appendix. Because it is difficult to count more than five FP in a cluster using the microscope scan technique, statistical relationships were established for both yellow and green FP based on the number of grams of each color mixed with the spray liquid prior to dissemination. For example, for the mixture of FP used in Trial 5 of Subtest 3, a single yellow FP observed on a rotorod statistically indicated a droplet about 18 micrometers in diameter and a cluster of 3 green FP indicated a droplet about 44 micrometers in diameter. Since the aspiration rate and collection efficiencies of H- and U-shaped rotorods are known, the dosage can be calculated from the expression

$$D = \frac{\rho}{R} \sum \frac{V_i N_i}{E_i} \qquad (2\text{-}2)$$

where

ρ = density of the liquid spray (mg cm^{-3})

R = aspiration rate of the rotorod (m^3 min^{-1})

V_i = volume of the droplet in the i^{th} size category (cm^3)

N_i = number of drops in the i^{th} size category counted on the rotorod

E_i = collection efficiency of the rotorod for a droplet in the i^{th} size category

An average of the H and U rotorod dosages was used in calculating the crosswind-integrated dosages.

In principle, use of both colors of FP in Trial 5 should have provided air dosage estimates for droplets with diameters less than about 53 micrometers. However, complications arose in the computation of air dosages because the number of single FP and the number of clusters of yellow and green FP on each rotorod were counted independently and no joint distribution was established for yellow and green FP. Thus, a cluster of 6 FP consisting of 5 yellow and 1 green FP could be reported as two drops, one drop with a single green FP and one drop with a cluster of 5 yellow FP. Because there is some likelihood that a mixture of yellow and green FP may occur in a single drop, dosage estimates based on the independent counts of the two colors of FP are subject to some uncertainty. In the absence of a knowledge of the joint probability distribution of the yellow and green FP, it was assumed that the independent statistical distribution for yellow FP was valid for all counts up to a cluster of 5 yellow FP and that the independent distribution for green FP was valid for clusters of 2 or more green FP. To the extent that these assumptions are invalid, the observed dosages may be spurious.

Air dosages measured by the cylindrical samplers were obtained from a chemical analysis of spray material leached from the samplers using the expression

$$D_c = \frac{M}{A\bar{u}\{s\}} \tag{2-3}$$

where

M = mass of material washed from the sampler

A = effective collection area of the sampler

$\bar{u}\{s\}$ = mean wind speed at sampler height

As noted above, no allocation of the dosage by droplet size is possible from this type of analysis.

SECTION 3

DEPOSITION AND DOSAGE MODELS

With the exception of the model for estimating deposition from dosage measurements suggested by Murray, et al., (1970), the models described below for calculating deposition and dosage from nearly-instantaneous sources are similar to the models described by Cramer, et al., (1972). The models are written for use with volume sources. The computer program incorporating the models uses an algorithm based on the work of Stenger (1973) to determine the placement and number of volume sources required to simulate a line source of finite length for any sampling positions and for any angle between the mean wind direction and the line source aircraft flight path. The models are essentially modifications of tilted plume models where the centroid of a particle or droplet cloud of a given settling velocity intersects the ground plane at a distance from the source and at an angle from the mean surface wind direction that are proportional to the residence time of the settling material in the layer between the source height and the ground. The inclination of the cloud trajectory from the horizontal is defined by $\tan^{-1}(V_s/\bar{u})$ where $\bar{u}$ is the effective transport speed for a particle or droplet with settling velocity V_s. Provision has been made in the models for partial reflection of the particles or droplets at the surface. Thus, particles or droplets dispersed upward by turbulence are assumed to be reflected downward at the top of the mixing layer, but the fraction of material γ reflected at the ground surface is a variable input parameter for each settling velocity V_s. The total deposition or dosage is obtained by summing, for all of the volume sources representing the line source, the calculated deposition or dosage for all settling velocity categories on a reference coordinate grid system.

The deposition models and dosage models used in the calculations are described respectively in Sections 3.1 and 3.2 below. For convenience in writing the model equations, the quantity 0^0 (zero to the zero power) is defined to be equal to unity.

3.1 DEPOSITION MODEL

The deposition Dep_i produced by a volume source comprised of particles or droplets with gravitational settling velocity V_{si} and reflection coefficient γ_i given by

$$
\begin{aligned}
Dep_i = \frac{f_i \, Q \, K \, (1 - \gamma_i)}{2\pi \, \sigma_y \, \sigma_z \, (x + x_z)} & \left\{ \exp\left[-\frac{1}{2} \left(\frac{y}{\sigma_y} \right)^2 \right] \right\} \\
& \left\{ \left[H + V_{si} x_z / \bar{u} \right] \left[\exp\left(-\frac{1}{2} \left(\frac{H - V_{si} x/\bar{u}}{\sigma_z} \right)^2 \right) \right] \right. \\
& + \sum_{a=1}^{\infty} \gamma_i^{a-1} \left\{ \left[2a \, H_m - H - V_{si} x_z / \bar{u} \right] \left[\exp\left(-\frac{1}{2} \left(\frac{2aH_m - H + V_{si} x/\bar{u}}{\sigma_z} \right)^2 \right) \right] \right. \\
& \left. \left. + \gamma_i \left[2a \, H_m + H + V_{si} x_z / \bar{u} \right] \left[\exp\left(-\frac{1}{2} \left(\frac{2aH_m + H - V_{si} x/\bar{u}}{\sigma_z} \right)^2 \right) \right] \right\} \right\}
\end{aligned}
\tag{3-1}
$$

where

f_i = fraction of the total source comprised of droplets in the i^{th} droplet size category

Q = source strength assigned to each point source

K = scaling coefficient used to convert input parameters to dimensionally consistent units

γ_i = fraction of the material in the i^{th} droplet-size category reflected at the surface (1 for complete reflection and 0 for no reflection)

H = release height

H_m = depth of the surface mixing layer

V_{si} = gravitational settling velocity for the i^{th} droplet-size category

$\bar{u}$ = mean transport wind speed

$$= \frac{\bar{u}_R \quad (z_2)^{1+p} - (z_1)^{1+p}}{(z_2 - z_1)(z_R)^p (1+p)} \tag{3-2}$$

$\bar{u}_R$ = mean wind speed at the reference level Z_R

p = wind power-law exponent

$$z_1 = \begin{cases} H - 2.15\sigma_z & ; \quad H \geq 2.15\sigma_z \\ 2 & ; \quad H \leq 2.15\sigma_z \end{cases} \tag{3-3}$$

$$z_2 = \begin{cases} H + 2.15\sigma_z & ; \quad H + 2.15\sigma_z \leq Hm \\ Hm & ; \quad H + 2.15\sigma_z > Hm \end{cases} \tag{3-4}$$

x_z = vertical virtual distance

$$= \begin{cases} \dfrac{\sigma_{zR}}{\sigma'_E} - x_{Rz} & ; \quad \sigma_{zR} \leq \sigma'_E x_{rz} \\ \beta x_{rz} \left(\dfrac{\sigma_{zR}}{\sigma'_E x_{rz}} \right)^{1/\beta} - x_{Rz} + x_{rz} (1 - \beta) & ; \quad \sigma_{zR} \geq \sigma'_E x_{rz} \end{cases} \tag{3-5}$$

σ_{zR} = standard deviation of the vertical concentration distribution at a distance x_{Rz} downwind from the source

σ'_E = standard deviation of the wind-elevation angle in radians at height H

β = vertical diffusion coefficient

x_{rz} = distance over which rectilinear vertical cloud expansion occurs downwind from an ideal point source

σ_z = the standard deviation of the vertical concentration distribution

$$= \sigma'_E x_{rz} \left[\frac{x + x_z - x_{rz}(1-\beta)}{\beta x_{rz}} \right]^{\beta} \tag{3-6}$$

σ_y = the standard deviation of the crosswind concentration distribution

$$= \left[\left(\sigma'_A(\tau)\, x_{ry} \left(\frac{x + x_y - x_{ry}\ (1 - \alpha)}{\alpha x_{ry}} \right)^{\alpha} \right)^2 + \left(\frac{\Delta\theta' x}{4.3} \right)^2 \right]^{1/2} \tag{3-7}$$

$\sigma'_A\{\tau\}$ = standard deviation of the azimuth wind angle in radians at height H measured over the source emission time τ

$$\sigma'_A\{\tau\} = \sigma'_A\{\tau_o\} \left(\frac{\tau}{\tau_o} \right)^{1/5} \quad ; \quad 1 \leq \tau_o \leq 600 \text{ seconds} \tag{3-8}$$

$\sigma'_A\{\tau_o\}$ = standard deviation of the azimuth wind angle in radians in the surface mixing layer measured over the reference time τ_o

x_{ry} = distance over which rectilinear crosswind cloud expansion occurs downwind from the virtual point source

α = crosswind diffusion coefficient

x_y = crosswind virtual distance

$$= \begin{cases} \dfrac{\sigma_{yR}}{\sigma'_A\{\tau\}} - x_{Ry} & ; \sigma_{yR} \leq \sigma'_A\{\tau\}\, x_{ry} \\[2ex] \alpha x_{ry} \left(\dfrac{\sigma_{yR}}{\sigma'_A(\tau)\ x_{ry}} \right)^{1/\alpha} - x_{Ry} + x_{ry}(1 - \alpha) & ; \sigma_{yR} > \sigma'_A\{\tau\}\, x_{ry} \end{cases} \tag{3-9}$$

σ_{yR} = standard deviation of the crosswind concentration distribution at a distance x_{Ry} downwind from the source

$\Delta\theta'$ = azimuth wind direction shear in radians for the layer containing the cloud

$$= \frac{\Delta\theta'}{\Delta z} \left(z_2 - z_1\right) \tag{3-10}$$

$\frac{\Delta\theta'}{\Delta z}$ = rate change of wind direction in radians with height in the surface mixing layer

Murray, et al., (1970) suggested that the following relationship could be used to estimate ground deposition from dosage measurements of FP-tagged droplets using rotorod samplers placed near the ground:

$$Dep_i = V_{si} D_i \tag{3-11}$$

where

Dep_i = mass deposition of droplets in the i^{th} category (mg m^{-2})

V_{si} = mean settling velocity of droplets in the i^{th} category (m min^{-1})

D_i = dosage due to droplets in the i^{th} category measured from the rotorod data (mg min m^{-3})

3.2 DOSAGE MODEL

The dosage DOS_i produced by a volume source comprised of particles or droplets with gravitational settling velocity V_{si} and reflection coefficient γ_i given by

$$DOS_i = \frac{f i Q K}{2 \pi \bar{u} \sigma_y \sigma_z} \left\{ \exp\left[-\frac{1}{2} \left(\frac{y}{\sigma_y} \right)^2 \right] \right\} \tag{3-12}$$

$$
\left\{ \sum_{a=o}^{\infty} \gamma_i^{\,a} \exp\left[-1/2 \left(\frac{2aH_m - H + z + V_{si}x/\bar{u}}{\sigma_z} \right)^2 \right] \right.
$$

$$
+ \gamma_i^{\,a+1} \exp\left[-1/2 \left(\frac{2aH_m + H + z - V_{si}x/\bar{u}}{\sigma_z} \right)^2 \right] \Bigg]
$$

$$
+ \sum_{a=1}^{\infty} \left[\gamma_i^{\,a} \exp\left[-1/2 \left(\frac{2aH_m + H - z - V_{si}x/\bar{u}}{\sigma_z} \right)^2 \right] \right.
\qquad \text{(3-12) Continued}
$$

$$
\left. \left. + \gamma_i^{\,a-1} \exp\left[-1/2 \left(\frac{2aH_m - H - z + V_{si}x/\bar{u}}{\sigma_z} \right)^2 \right] \right] \right\}
$$

where all the terms in Equation (3-12) have been defined above.

SECTION 4

SOURCE AND METEOROLOGICAL INPUTS

Model inputs used in the deposition and dosage models described in Section 3 are given below. The source inputs for the seven trials in Subtest 3 of the 70-11 Test Series are described in Section 4.1 and the meteorological inputs are described in Section 4.2. Inputs used to calculate the normalized deposition and dosage profiles presented in Section 5.3 are given in Section 4.3.

4.1 SOURCE INPUTS FOR SUBTEST 3, 70-11 TEST SERIES

The fraction of the total mass of liquid spray droplets in various droplet size categories f_i and the settling velocity representative of drops in each size category V_{si} are among the source inputs required by the deposition and dosage models. The points in Figure 4-1 are estimates of the cumulative mass versus droplet size categories obtained from an analysis of stains on the Printflex cards for all seven trials in Subtest 3. The solid line in the figure was calculated by fitting a log-normal distribution to the points using a least-square regression technique. Because Figure 4-1 shows that the measured distribution is approximately log-normal between the 10- and 90-percent limits of the mass distribution and curvilinear outside these limits, only the points between the 10- and 90-percent limits were used in calculating the fitted line. The "average" cumulative mass distribution was then subdivided into 17 droplet-size categories and values of f_i selected for each category from the fitted line for use in the calculations. The settling velocities V_{si}, calculated using the technique described by McDonald (1960) for the droplet representing the geometric mean diameter of each of the intervals, are shown in Table 4-1 along with the values of f_i for the interval. Since air temperature and pressure affect the calculation of V_s, the values of V_{si} in Table 4-1 vary for each trial.

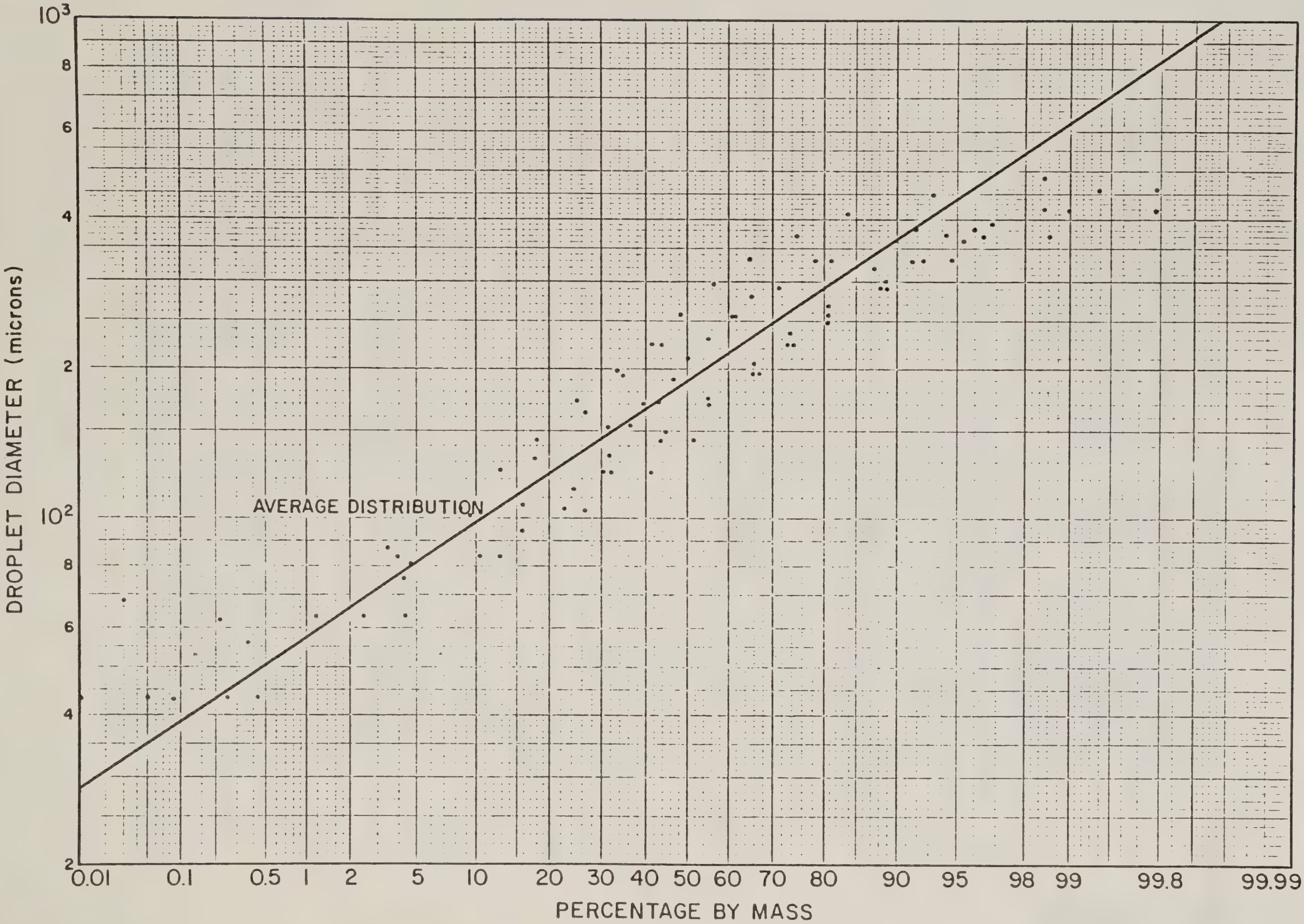

FIGURE 4-1. Average drop size distribution for Trials 1 through 7.

TABLE 4-1

MASS FRACTIONS f_i, SETTLING VELOCITIES V_{si}, AND REFLECTION COEFFICIENTS γ_i USED IN THE CALCULATIONS

Geometric Mean Droplet Diameter (micrometers)	Fraction of Mass f_i	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5		Trial 6		Trial 7	
		Settling Velocity V_{si} (m sec^{-1})	Reflection Coefficient γ_i	Settling Velocity V_{si}	Reflection Coefficient γ_i	Settling Velocity V_{si}	Reflection Coefficient γ_i	Settling Velocity V_{si}	Reflection Coefficient γ_i	Settling Velocity V_{si}	Reflection Coefficient γ_i	Settling Velocity V_{si}	Reflection Coefficient γ_i	Settling Velocity V_{si}	Reflection Coefficient γ_i
11.2	1×10^{-1}	5.66×10^{-3}	.77	5.58×10^{-3}	.77	5.61×10^{-3}	.77	5.72×10^{-3}	.77	5.85×10^{-3}	.77	5.72×10^{-3}	.77	5.71×10^{-3}	.77
33.1	9×10^{-1}	3.07×10^{-2}	.68	3.03×10^{-2}	.68	3.05×10^{-2}	.68	3.11×10^{-2}	.68	3.18×10^{-2}	.68	3.11×10^{-2}	.68	3.10×10^{-2}	.68
47.2	9×10^{-3}	6.25×10^{-2}	.59	6.17×10^{-2}	.59	6.20×10^{-2}	.59	6.32×10^{-2}	.59	6.47×10^{-2}	.59	6.32×10^{-2}	.59	6.31×10^{-2}	.59
64.3	2×10^{-2}	1.16×10^{-1}	.46	1.14×10^{-1}	.46	1.15×10^{-1}	.46	1.17×10^{-1}	.46	1.20×10^{-1}	.45	1.17×10^{-1}	.46	1.17×10^{-1}	.46
78.6	3×10^{-2}	1.73×10^{-1}	.32	1.71×10^{-1}	.32	1.72×10^{-1}	.32	1.75×10^{-1}	.31	1.79×10^{-1}	.30	1.75×10^{-1}	.31	1.75×10^{-1}	.31
91.6	4×10^{-2}	2.26×10^{-1}	.18	2.21×10^{-1}	.19	2.25×10^{-1}	.18	2.28×10^{-1}	.18	2.33×10^{-1}	.16	2.28×10^{-1}	.18	2.28×10^{-1}	.18
109.3	.1	2.76×10^{-1}	.06	2.73×10^{-1}	.07	2.74×10^{-1}	.06	2.78×10^{-1}	.06	2.84×10^{-1}	.04	2.78×10^{-1}	.06	2.78×10^{-1}	.06
132.5	.1	3.58×10^{-1}	0	3.51×10^{-1}	0	3.56×10^{-1}	0	3.62×10^{-1}	0	3.70×10^{-1}	0	3.62×10^{-1}	0	3.62×10^{-1}	0
155.1	.1	4.65×10^{-1}	0	4.60×10^{-1}	0	4.62×10^{-1}	0	4.70×10^{-1}	0	4.80×10^{-1}	0	4.70×10^{-1}	0	4.69×10^{-1}	0
189.5	.2	6.25×10^{-1}	0	6.19×10^{-1}	0	6.21×10^{-1}	0	6.31×10^{-1}	0	6.45×10^{-1}	0	6.31×10^{-1}	0	6.31×10^{-1}	0
230.9	.1	8.42×10^{-1}	0	8.35×10^{-1}	0	8.37×10^{-1}	0	8.48×10^{-1}	0	8.66×10^{-1}	0	8.48×10^{-1}	0	8.48×10^{-1}	0
268.6	.1	9.86×10^{-1}	0	9.78×10^{-1}	0	9.81×10^{-1}	0	9.94×10^{-1}	0	1.02	0	9.93×10^{-1}	0	9.93×10^{-1}	0
321.6	.1	1.21	0	1.20	0	1.20	0	1.22	0	1.24	0	1.22	0	1.22	0
389.5	4×10^{-2}	1.53	0	1.51	0	1.52	0	1.54	0	1.57	0	1.59	0	1.54	0
456.3	3×10^{-2}	1.84	0	1.82	0	1.83	0	1.85	0	1.89	0	1.85	0	1.85	0
555.9	2×10^{-2}	2.21	0	2.19	0	2.19	0	2.22	0	2.27	0	2.22	0	2.22	0
706	1×10^{-2}	2.76	0	2.73	0	2.74	0	2.78	0	2.84	0	2.78	0	2.78	0

The reflection coefficients γ_i in Table 4-1 were selected from the hypothetical curve shown in Figure 4-2 relating settling velocity with the reflection coefficient. This curve, previously used by Dumbauld, Rafferty and Cramer (1976) in modeling deposition downwind from aerial spray releases, is based on the following general argument. All droplets with settling velocities greater than 30 centimeters per second are assumed to have a reflection coefficient of zero and thus are assumed to be deposited on the ground without reflection. Droplets with settling velocities less than 0.1 centimeters per second are assumed to have a reflection coefficient of 1 and thus are assumed to be completely reflected. It is further assumed that the reflection coefficient is linearly related to the settling velocity for velocities from 5 to 30 centimeters per second, with a value of 0.5 arbitrarily assigned to the reflection coefficient γ when the settling velocity is 10 centimeters per second. For settling velocities less than 5 centimeters per second, the reflection coefficient is assumed to asymptoticaly approach 1 as the settling velocity decreases to zero.

The technique described in Section 2.3 for calculating observed dosages from rotorod sampler data permits calculation of dosages due to droplets with diameters less than about 53 micrometers. Values of the mass fractions f_i, the settling velocities V_{si}, and the reflection coefficients γ_i used in the calculation of air dosages for comparison with the rotorod data for Trial 5 are shown in Table 4-2.

The remaining source inputs required by the computerized models are listed in Table 4-3. Values of the source strength Q and release height H were based on measurements made during the trials by DPG personnel. The source dimensions σ_{xo}, σ_{yo} and σ_{zo}, estimated from observations by DPG personnel of the cloud after aircraft wake effects had subsided were set to 9.3 meters for all trials in Subtest 3. Values of the length of the release line L and the angle measured clockwise between the downwind grid axis and mean wind direction $\angle$ given in Table 4-3, while not appearing directly in the model equations presented

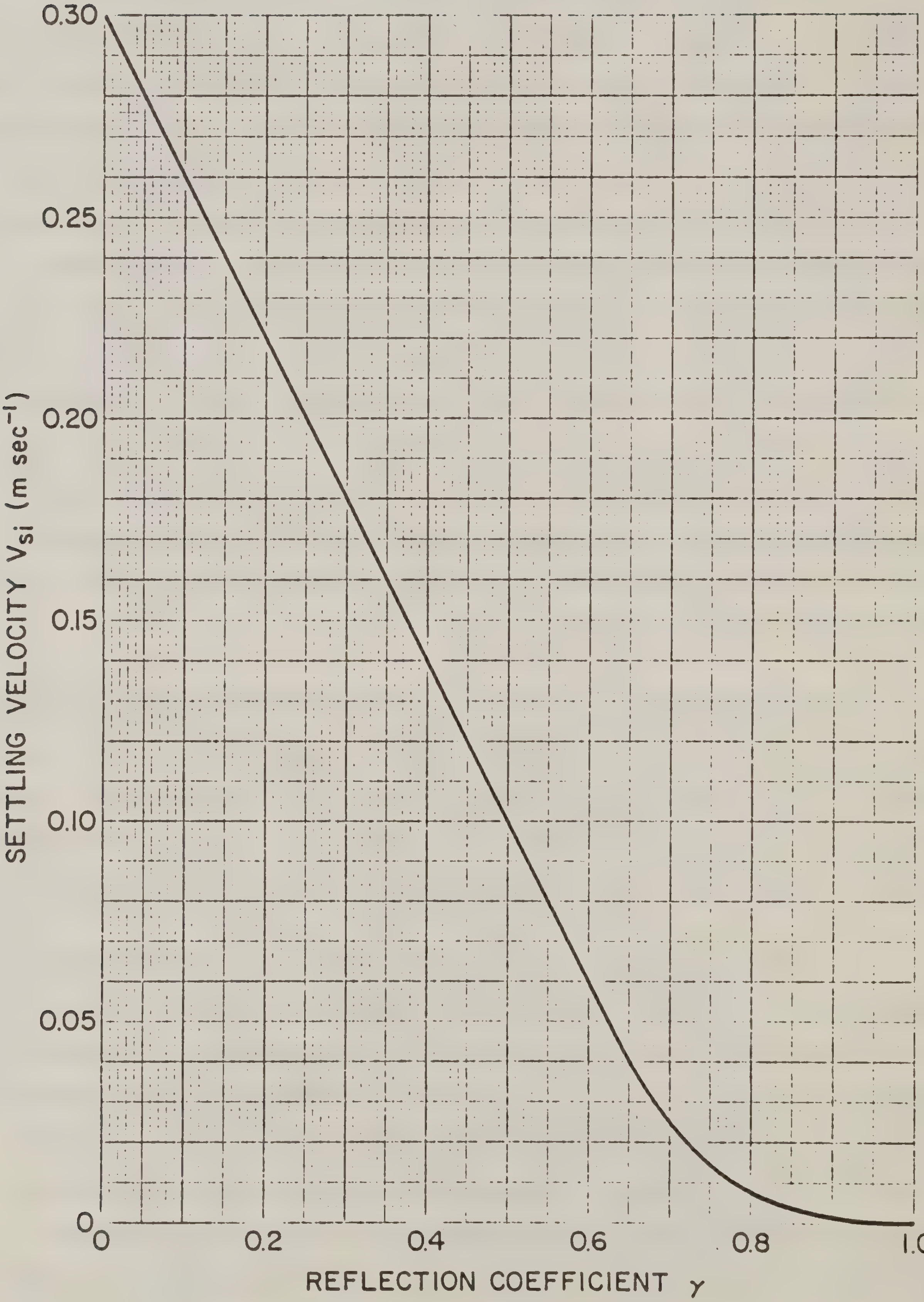

FIGURE 4-2. Relationship between the gravitational settling velocity V_{si} and the reflection coefficient γ at the ground surface.

TABLE 4-2

FRACTIONS OF MASS f_i, SETTLING VELOCITIES V_{si}, AND REFLECTION COEFFICIENTS γ_i USED IN CALCULATIONS OF DOSAGE FOR COMPARISON WITH ROTOROD MEASUREMENTS FROM TRIAL 5

Geometric Mean Droplet Diameter (micrometers)	Fraction of Mass f_i	Settling Velocity V_{si} (m sec^{-1})	Reflection Coefficient γ_i
14.2	1×10^{-4}	5.85×10^{-3}	.77
30.9	3×10^{-4}	2.71×10^{-2}	.69
36.0	6×10^{-4}	3.68×10^{-2}	.66
42.0	2×10^{-3}	5.00×10^{-2}	.62
49.3	3.8×10^{-3}	6.89×10^{-2}	.57

TABLE 4-3

SOURCE STRENGTH Q, RELEASE HEIGHT H, SOURCE DIMENTIONS σ_{xo}, σ_{yo}, σ_{zo}, LENGTH OF RELEASE LINE L, AND ANGLE ∠ FOR TRIALS IN SUBTEST 3

Trial Number	Q (kg)	H (m)	$\sigma_{xo}=\sigma_{yo}=\sigma_{zo}$ (m)	L (m)	∠ (degrees)
1	406.2	70	9.3	1955	16
2	406.4	218	9.3	1464	0
3	405.5	104	9.3	1477	18
4	407.3	130	9.3	1469	21
5	615.8	110	9.3	1573	20
6	563.6	148	9.3	2003	3
7	858.4	129	9.3	2815	0

in Section 3, are used by the computer program to place the volume sources along the flight path of the aircraft.

The Murray, et al. (1970) procedure for estimating deposition requires as inputs the gravitational settling velocities or the various drop-size categories (see Equation (3-11). Table 4-4 lists the mean drop diameters and settling velocities associated with clusters of yellow and green FP used in the calculation of ground deposition from rotorod dosage measurements using the Murray, et al. (1970) procedure.

4.2 METEOROLOGICAL INPUTS FOR SUBTEST 3, 70-11 TEST SERIES

Meteorological input parameters used in the model calculations are shown in Table 4-5. These inputs were developed from meteorological data supplied by DPG. The reference wind speeds $\bar{u}_R$ are the wind speeds at the reference height z_R of 1 meter. The wind-profile exponents p shown in the table were obtained from plots of time-averaged wind-speed profiles for Towers 00 and 12 (see Figure 2-1) and from pilot ballon (PIBAL) measurements made at the time of spray release. The PIBAL wind measurements were also used to estimate the depth of the surface mixing layer H_m on the basis of discontinuities in the wind-speed and/or wind-direction profiles indicative of the presence of stable layers. Both the tower and PIBAL wind profiles were used to obtain estimates of the mean wind direction and the vertical wind-direction shear $\Delta \theta' / \Delta z$ in the surface mixing layer. Profiles of the standard deviations of the wind azimuth angle σ'_A and wind elevation angle σ'_E were also constructed from time-averaged, bi-directional vane measurements made during the trials at Towers 00 and 12. Where possible, the values of σ'_A and σ'_E shown in Table 4-5 were selected from the turbulence measurements made during the trials for periods when the measurements at the various tower levels were consistent and also were within the range of values characteristic of the existing meteorological regime. However, because of large

TABLE 4-4

MEAN DROP DIAMETERS AND SETTLING VELOCITIES FOR DEPOSITION CALCULATIONS USING THE MURRAY, et al. (1970) METHOD

FP Cluster Count*	Mean Drop Diameter (μm)	Settling Velocity (m sec^{-1})
1Y	17.6	8.98×10^{-3}
2Y	22.2	1.43×10^{-2}
3Y	25.4	1.87×10^{-2}
4Y	27.9	2.26×10^{-2}
5Y	30.1	2.63×10^{-2}
2G	38.7	4.34×10^{-2}
3G	44.3	5.69×10^{-2}
4G	48.7	6.89×10^{-2}
5G	52.5	8.00×10^{-2}

* Y indicates clusters of yellow FP and G indicates green FP

TABLE 4-5

METEOROLOGICAL INPUTS FOR SUBTEST 3
OF THE 70-11 TEST SERIES

Trial Number	$\bar{u}_R$ (m sec^{-1})	p	$\Delta\theta'/\Delta z$ (rad m^{-1})	σ'_A ($\tau = 2.5$) (rad)	σ'_E (rad)	H_m (m)	Wind Direction (deg)
1	5.47	.117	2.9×10^{-4}	.01745	.01745	140	156
2	2.00	.0852	-9.97×10^{-4}	.05236	.05236	256	140
3	5.52	.150	-1.27×10^{-3}	.01745	.01745	175	158
4	3.38	.179	-3.23×10^{-4}	.01745	.01745	150	161
5	4.99	.0849	1.78×10^{-3}	.03491	.03491	355	160
6	3.53	.0603	4.61×10^{-3}	.03491	.03491	175	143
7	3.63	.119	1.45×10^{-3}	.03491	.03491	204	140

inconsistencies in the turbulence data, appropriate values of σ'_A and σ'_E were assigned for most of the trials after careful considerations of the other meteorological measurements and the turbulence climatology of Dugway Proving Ground. The values of σ'_A in the table, which are for a source function time τ of 2.5 seconds, were derived from 10-minute σ'_A values using the expression

$$\sigma'_A \{ \tau = 2.5 \} = \sigma'_A \{ 600 \text{ seconds} \} \left(\frac{2.5}{600} \right)^{1/5} \tag{4-1}$$

due to Cramer, et al. (1972) and others.

4.3 MODEL INPUTS FOR THE CALCULATION OF NORMALIZED DEPOSITION AND DOSAGE PROFILES

Source and meteorological inputs used in calculating the normalized deposition and dosage profiles described in Section 5.3 are given in Table 4-6. These inputs correspond to a typical elevated line source release under neutral atmospheric stability conditions. Note that the calculations were made for two wind profiles. The net result of using the two combinations of $\bar{u}_R$ and p shown in Table 4-6 is that the cloud transport wind speed $\bar{u}$ for the second case ($\bar{u}_R = 5$; $p = .08$) is nearly twice the transport speed for the first case ($\bar{u}_R = 2$; $p = .13$) throughout the downwind travel of the cloud. The normalized calculations were performed using a unit source strength ($Q = 1$) for each droplet size category so direct comparisons of the effects of variations in settling velocity and wind speeds could be made. In all of the calculations of normalized deposition and dosage profiles, it was assumed that the line source was oriented perpendicular to the mean wind direction.

TABLE 4-6

SOURCE AND METEOROLOGICAL INPUTS USED IN THE NORMALIZED DEPOSITION AND DOSAGE CALCULATIONS

Parameter	Value
H (m)	100
$\sigma_{xo} = \sigma_{yo} = \sigma_{zo}$ (m)	10
L (m)	1500
$\angle$ (degrees)	0
$\bar{u}_R$ (m sec^{-1})	2, 5
p	0.13, .08
$\Delta \theta' / \Delta z$ (rad m^{-1})	0
σ'_A $\{\tau = 2.5\}$ (rad)	0.03491
σ'_E (rad)	0.03491
H_m (m)	350

The settling velocities and reflection coefficients used to calculate normalized deposition and dosage profiles are listed in Table 4-7 as functions of droplet diameter. The settling velocities were calculated using the McDonald (1960) procedures assuming an ambient air temperature of 6.4 degrees Celsius, a pressure of 880 millibars and a droplet density of 0.93 grams per cubic centimeter.

TABLE 4-7

SETTLING VELOCITIES AND REFLECTION COEFFICIENTS USED IN THE NORMALIZED DEPOSITION AND DOSAGE CALCULATIONS

Droplet Diameter (micrometers)	Settling Velocity V_{si} (m sec^{-1})	Reflection Coefficient γ_i
13.1	5×10^{-3}	.93
18.6	1×10^{-2}	.78
26.3	2×10^{-2}	.72
41.5	5×10^{-2}	.62
58.7	1×10^{-1}	.50
83.1	2×10^{-1}	.25
159	5×10^{-1}	0
265	1	0
485	2	0

SECTION 5

RESULTS OF THE STUDY

Comparisons of model predictions with observed deposition and dosage parameters are discussed in Sections 5.1 and 5.2. Section 5.3 compares the observed deposition with the deposition calculated by following the suggested procedures of Murray, et al. (1970). A discussion of calculated normalized deposition and dosage profiles that illustrate the effects of wind speed, settling velocity and other parameters on deposition and dosage is presented in Section 5.4. The results of the study are summarized in Section 5.5.

5.1 COMPARISON OF CALCULATED AND OBSERVED DEPOSITION

Profiles of crosswind integrated deposition versus downwind distance from the elevated line source for Trials 1 through 6 of Subtest 3, 70-11 Test Series were calculated using Equation (3-1), the source input data in Tables 4-1 and 4-3, and the meteorological inputs in Table 4-5. Model calculations were made for the location of each of the Printflex deposition samplers on the dense inner grid array shown in Figure 2-1. Equation (2-1) was then used to obtain calculated profiles of crosswind-integrated deposition which are shown with the observed crosswind-integrated deposition profiles in Figures 5-1 through 5-6. Model calculations were not made for Trial 7 of Subtest 3 because one of the two spray tanks used on the aircraft for Trial 7 malfunctioned and began to disseminate material only after the aircraft reached the approximate center of the sampling grid. Consequently, it was not possible to correctly partition the source strength along the release line for use in model calculations.

Figure 5-1 through 5-6 show generally good agreement between calculated and observed crosswind-integrated deposition, especially beyond a distance of about 1 kilometer downwind from the source. There are several possible reasons why

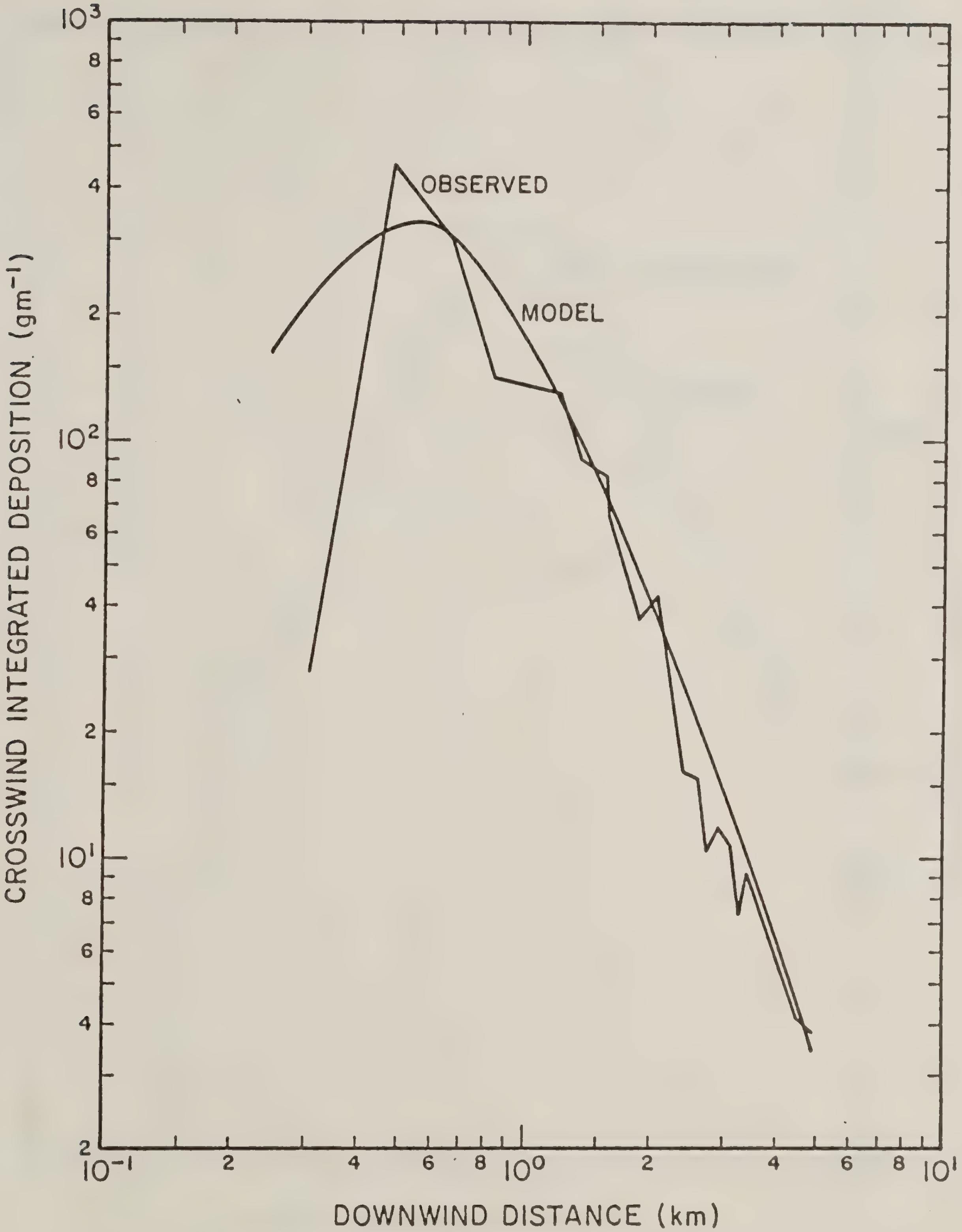

FIGURE 5-1. Profiles of model and observed crosswind-integrated deposition for Trial 1.

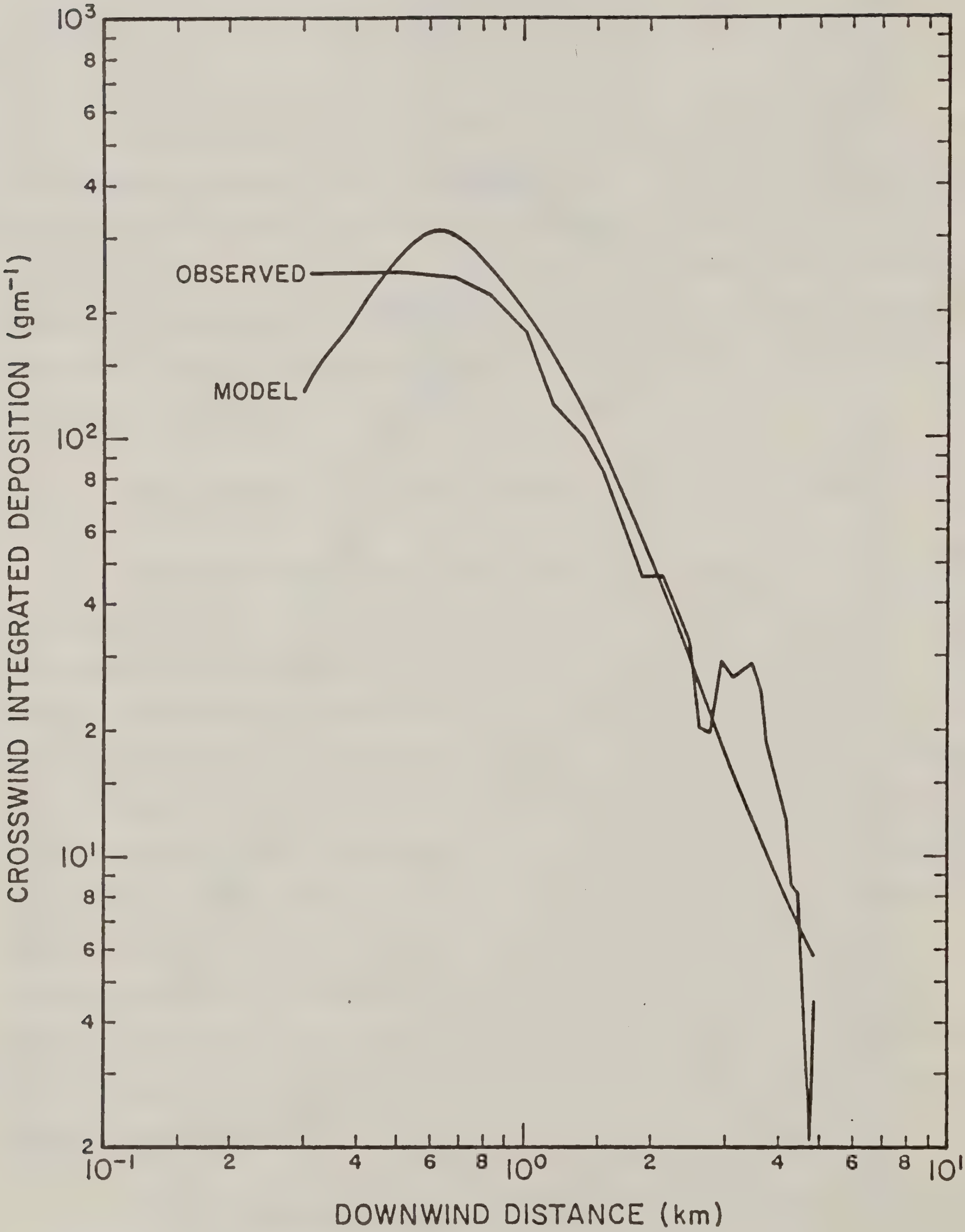

FIGURE 5-2. Profiles of model and observed crosswind-integrated deposition for Trial 2.

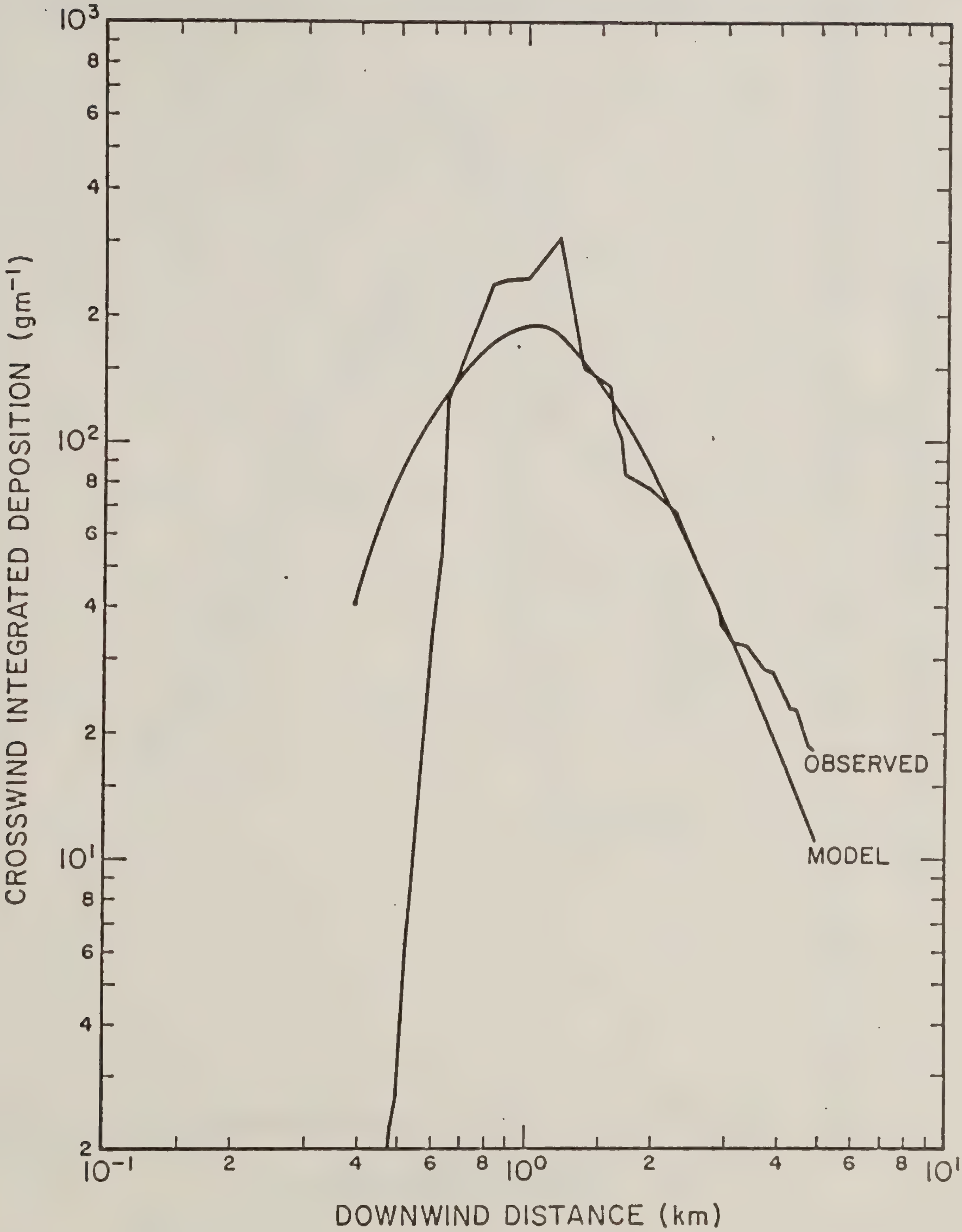

FIGURE 5-3. Profiles of model and observed crosswind-integrated deposition for Trial 3.

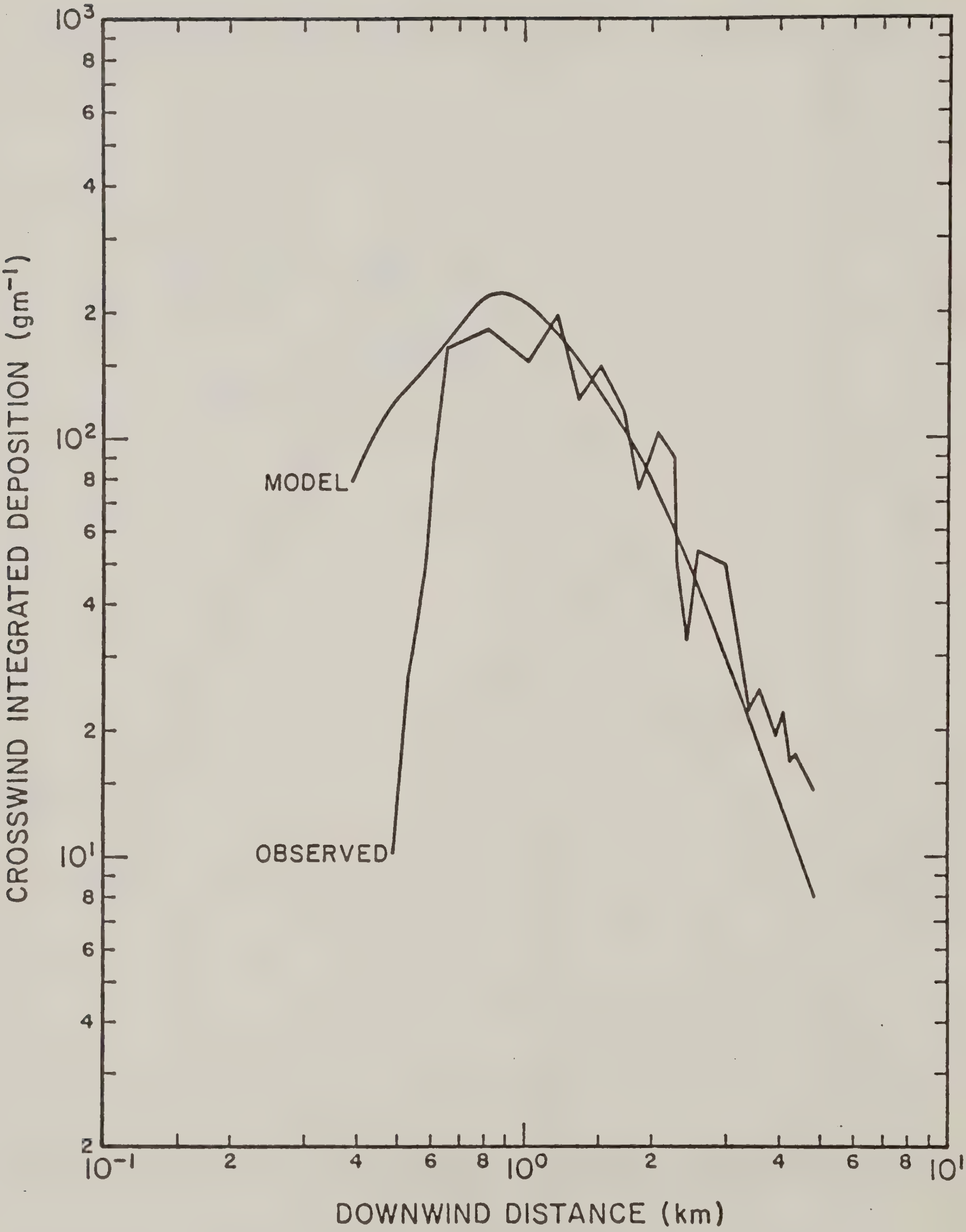

FIGURE 5-4. Profiles of model and observed crosswind-integrated deposition for Trial 4.

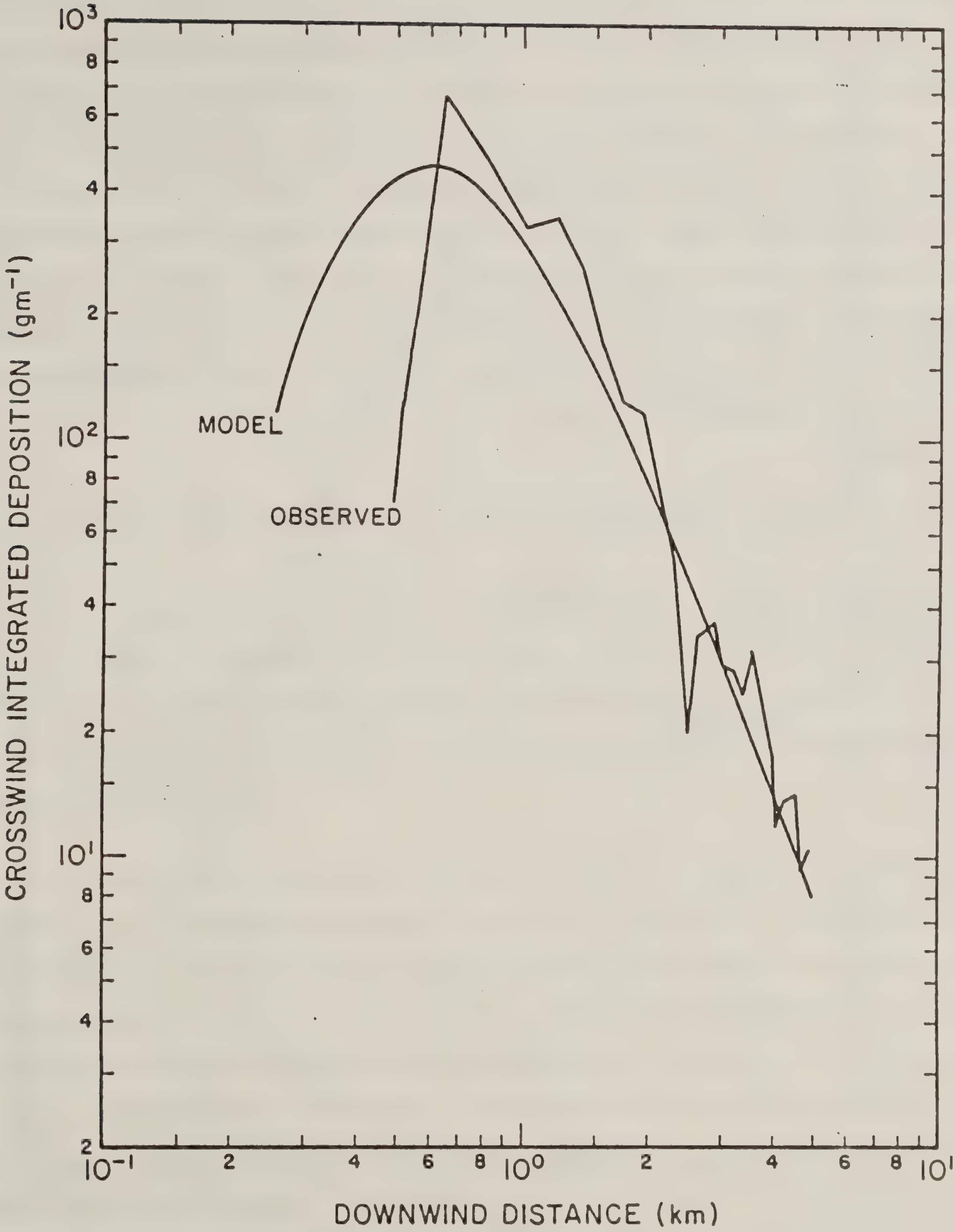

FIGURE 5-5. Profiles of model and observed crosswind-integrated deposition for Trial 5.

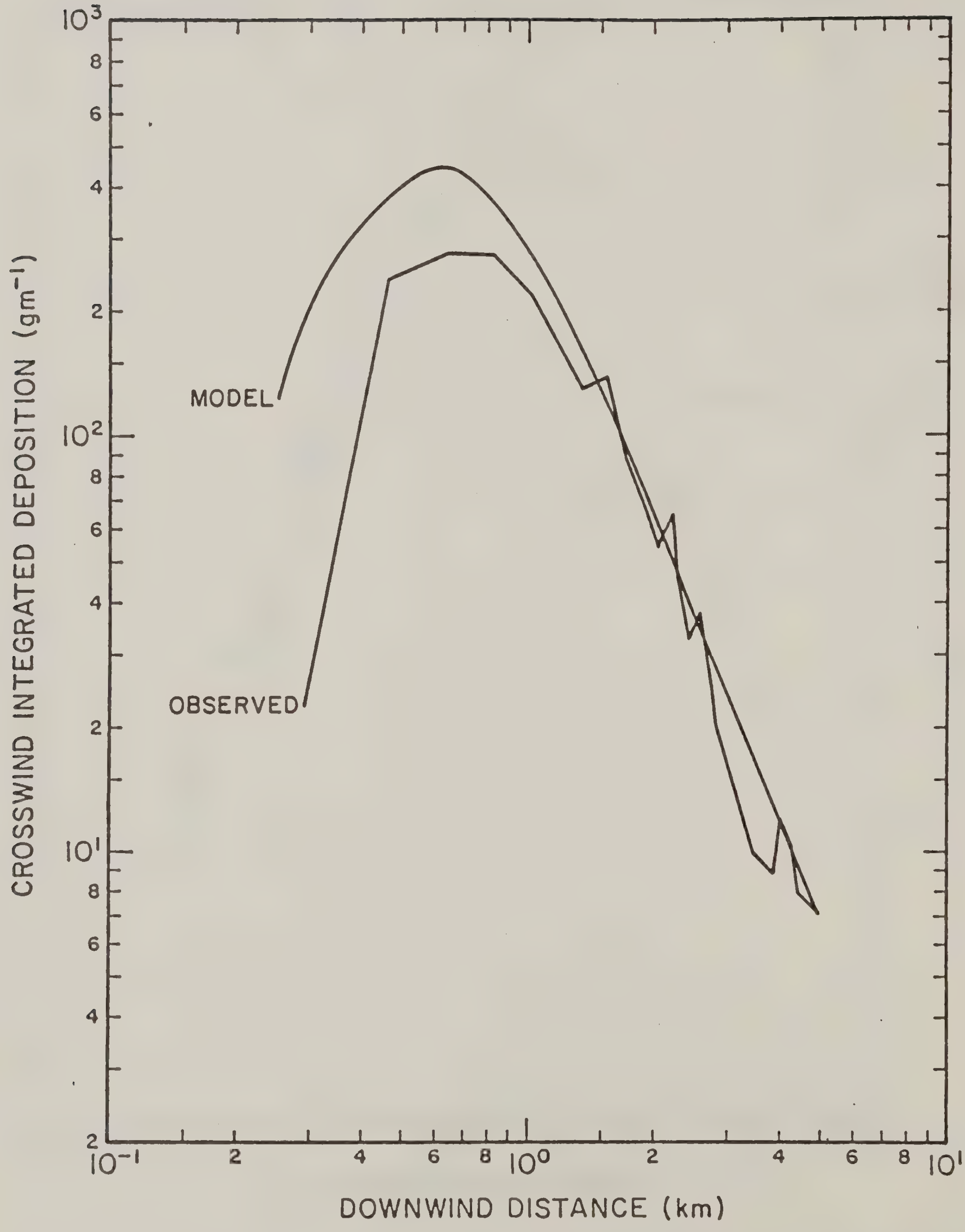

FIGURE 5-6. Profiles of model and observed crosswind-integrated deposition for Trial 6.

differences in estimated and observed deposition can occur close to the release line. First, as noted in Section 2.2, the release rate of material appeared to be nonuniform in many of the trials. While use of crosswind-integrated deposition for comparison purposes minimizes the effects of nonuniform release rates, errors in the total source strength, calculated by multiplying the release rate by the time required for the aircraft to traverse the estimated line length, can affect the model deposition estimates. Second, the model expressions for deposition and dosage do not explicitly consider aircraft wake effects which act to depress the cloud centroid near the release line and to increase deposition through the action of aircraft wake vortices.

5.2 COMPARISON OF CALCULATED AND OBSERVED DOSAGE

As explained in Section 2.3, observed dosage estimates were available for only Trial 5 of Subtest 3, 70-11 Test Series. Estimates of airborne dosages due to droplets with diameters less than about 53 micrometers were obtained from rotorod samplers; total dosages due to droplets of all diameters were obtained from the cylindrical samplers.

Observed and calculated crosswind-integrated dosages due to droplets less than 53 micrometers in diameter are shown in Figure 5-7. The calculated dosage profile in Figure 5-7 was obtained by first using Equation (3-12), the source inputs in Tables 4-2 and 4-3, and the meteorological inputs in Table 4-5 to calculate dosages due to droplets with diameters less than 53 micrometers at all the positions where rotorod samplers were located. Dosages were calculated at a height of 1.5 meters above the ground, the measurement height of the rotorod and cylindrical samplers. Model estimates of crosswind-integrated dosage were then obtained by using the procedure outlined in Section 2.3 for computing crosswind-integrated dosages from the measured dosages at each rotorod position.

Profiles of model estimates of crosswind-integrated total dosage and profiles of observed total dosage measured by the cylindrical samplers during Trial 5 are shown in Figure 5-8. In this case, the model estimates were obtained in the same manner as described above for droplets less than 53 micrometers in diameter, except that the source inputs for droplets of all diameters given in Table 4-1 were used in the calculations.

Figures 5-7 and 5-8 show that the model underestimates the observed crosswind-integrated air dosages due to droplets less than 53 micrometers in diameter (Figure 5-7) by about an order of magnitude but, on the other hand, performs rather well in estimating crosswind-integrated total dosage (Figure 5-8). As explained in Section 2, the observed dosages from rotorod samplers for droplets less than 53 micrometers in diameter were obtained by counting clusters of FP and this counting procedure could lead to errors in the observed dosages. In particular, the independent counting of yellow and green FP could lead to overestimation of observed dosages. The observed dosages from the cylindrical samplers were obtained by chemical analysis and thus were not influenced by the FP counting procedure. Another reason for model underestimation of dosages from droplets with diameters less than 53 micrometers may be due to the fact that the source strength used in the calculations for these droplets were obtained by counting drop stains on Printflex cards. Inspection of Figure 4-1, based on the analysis of drops depositing on Printflex cards, shows that less than seven-tenths of one percent of the total amount of material released from the aircraft was contained in droplets less than 53 micrometers. Also, as explained in Section 4, droplets of these diameters probably do not deposit efficiently and are reflected. Thus, estimates of the source strength for these droplets that are based on deposition data probably underestimate the true source strength by at least a factor of two. Further, it is often difficult to obtain accurate counts of stains representing drops in this size because of background (dirt) interference on the cards. A combination of these difficulties could easily lead to an underestimation of airborne dosages for droplets with diameters less than 53 micrometers without significantly affecting the model estimates of total deposition on the ground.

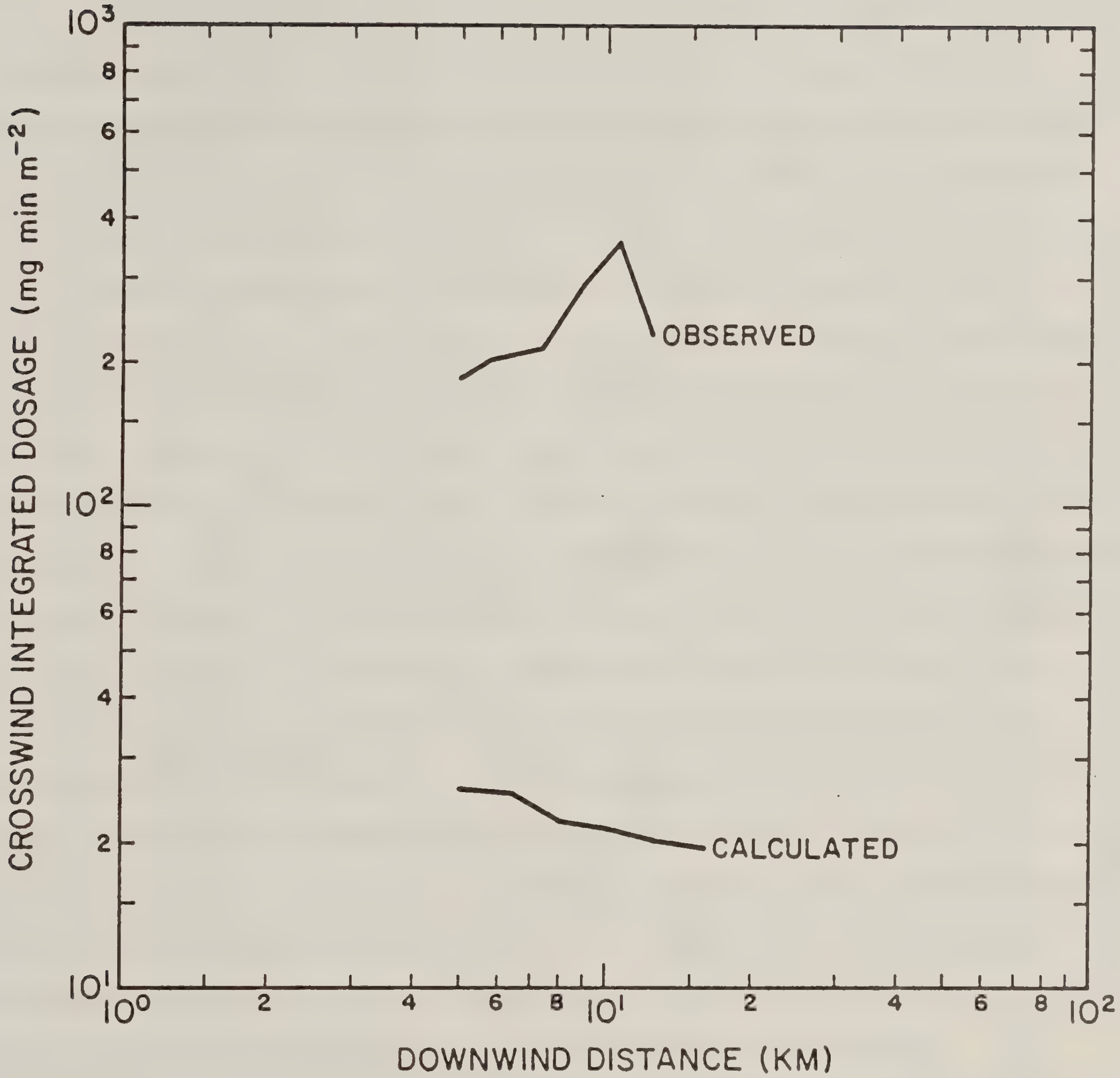

FIGURE 5-7. Observed and calculated crosswind-integrated dosages due to droplets less than 53 micrometers in diameter for Trial 5.

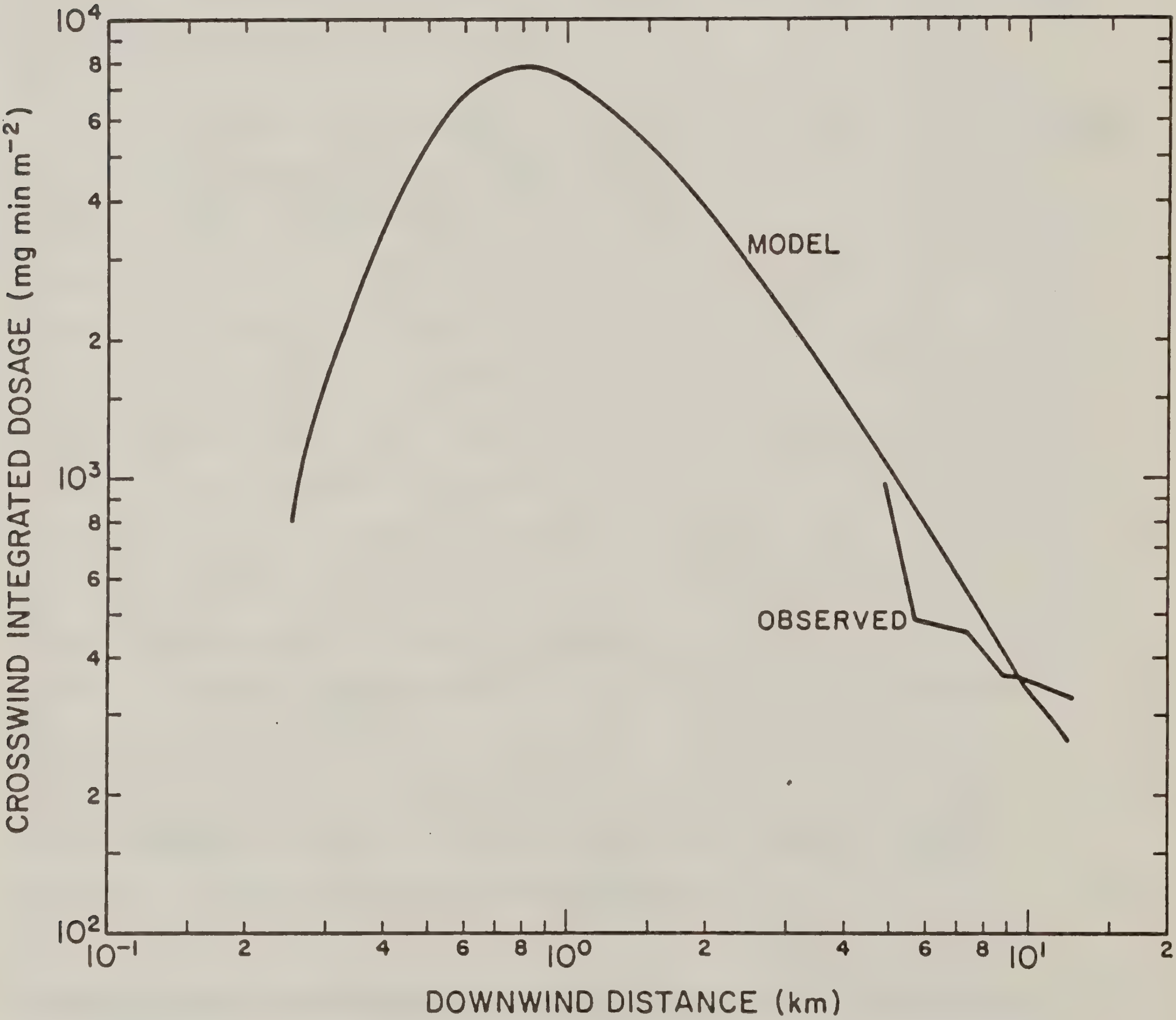

FIGURE 5-8. Model and observed crosswind-integrated dosages for Trial 5. Observed dosages were obtained from the cylindrical samplers.

5.3 ESTIMATED DEPOSITION OF SMALL DROPLETS FROM DOSAGE MEASUREMENTS FROM TRIAL 5

Figure 5-9 compares the crosswind-integrated deposition of small droplets calculated using Equation (3-11) (suggested by Murray, et al., 1970) with the measurements of crosswind-integrated deposition of small droplets obtained from the Printflex cards. The dosage measurements of droplets less than 53 micrometers in diameter for use in Equation (3-11) were obtained, using Equation (2-2), independently for the H and U rotorod data. The dosage data from both types of rotorods were then used in Equation (3-11), in conjunction with the inputs in Table 4-4, to estimate the surface deposition beneath the sampler. Crosswind-integrated deposition was calculated from Equation (2-1) and the averages of the crosswind-integrated deposition from the H and U rotorod data was plotted versus distance from the line source. The dashed line in Figure 5-9 shows this profile. The measured crosswind-integrated deposition estimated from the Printflex card data, shown by the solid line in Figure 5-9, was obtained by calculating the contribution of drops less than 63 micrometers in diameter to the total deposition on each card and using Equation (2-1) to obtain the crosswind-integrated deposition. The size category with an upper limit of 63 micrometers was the nearest interval to 53 micrometers which was used in the analysis of the Printflex cards. As inspection of Figure 5-9 shows, the crosswind-integrated deposition estimated from Equation (3-11) for droplets less than 53 micrometers does not differ greatly from the measurements obtained from Printflex cards for droplets less than 63 micrometers despite this slight discrepancy.

5.4 NORMALIZED DEPOSITION AND DOSAGE PROFILES

Calculation of deposition and dosage profiles were made to illustrate the relative effects of wind speed and assumptions regarding the reflection coefficients for nine settling velocity categories corresponding to drop diameters ranging from about 13 to 485 micrometers. The profiles were calculated using the inputs described

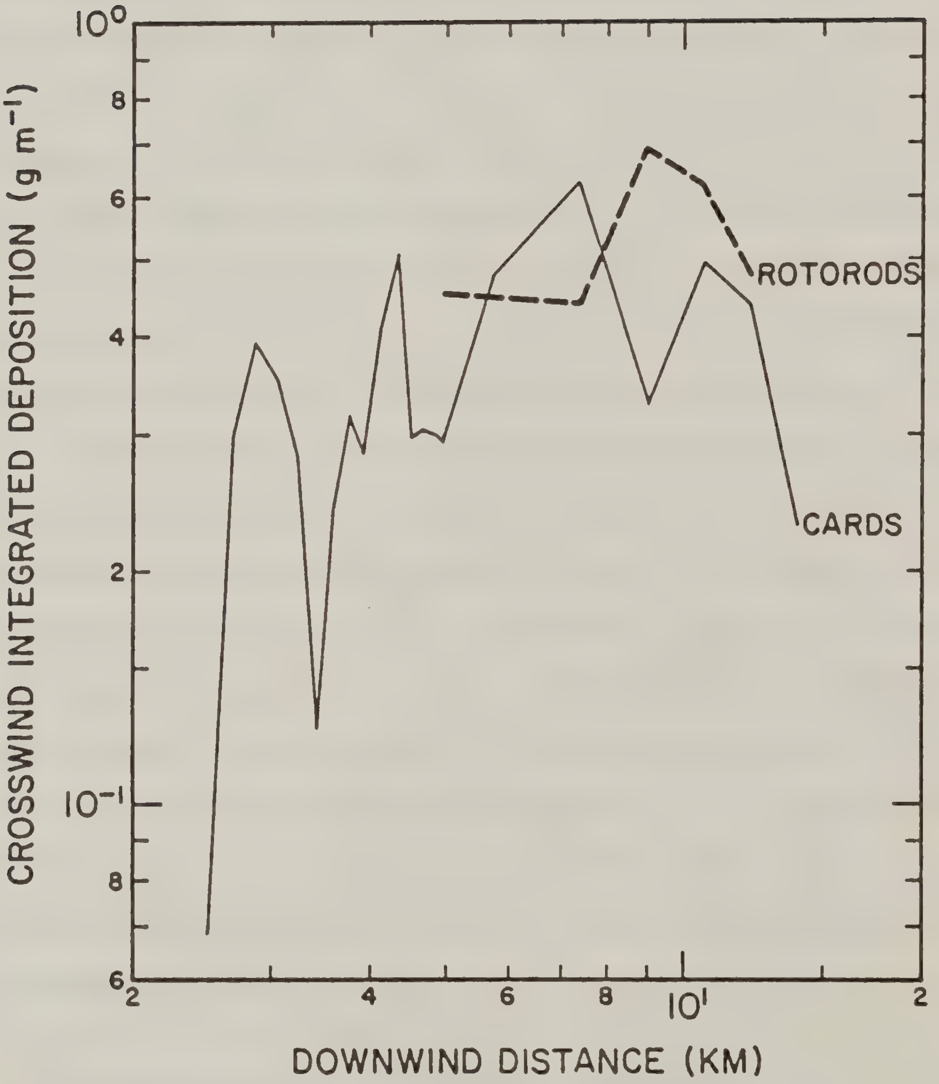

FIGURE 5-9. Dashed line shows crosswind-integrated deposition of small droplets calculated from rotorod data using the technique suggested by Murray et al. (1970); solid line shows the corresponding deposition from Printflex card samplers.

in Section 4.3 for a typical line source configuration and neutral atmospheric stabilility conditions. Figures 5-10 and 5-11 respectively show profiles of normalized deposition for cloud transport speeds of about 8.5 miles per hour ($\bar{u}_R = 2$ m sec^{-1}; $p = 0.13$) and 16.6 miles per hour ($\bar{u}_R = 5$ m sec^{-1}, $p = .08$) over most of the distance of travel. Comparison of the profiles in Figures 5-10 and 5-11 shows the expected increase in distance to the maximum peak deposition and corresponding decrease in magnitude of the peak deposition as wind speed increases for the larger droplets whose trajectories are ballistic in nature. At the same time, the distance to maximum peak dosage and the magnitude of deposition for those droplets governed by diffusion/transport processes are not nearly as affected by changes in the transport wind speed and there is little difference between the profiles shown in Figures 5-10 and 5-11. The effects of increasing reflection at the ground as droplet diameters decrease are also indicated in the figures by the presence of secondary maximums in the deposition profiles as the diameters decrease. Larger droplets reach ground-level and deposit while droplets in smaller size categories reach the air-earth interface and are reflected upwards. Upon reaching the top of the surface mixing layer, they are then reflected downwards, thus increasing deposition at longer downwind distances above that expected in the absence of partial or total reflection. This secondary maximum is not evident in the observed crosswind-integrated deposition profiles described in Section 5.1 because sufficient data were not available to plot profiles at the longer distances and the source strength of droplets below 100 micrometers was small in comparison to larger droplets. However, this secondary maximum was observed in data from spray trials at Dugway Proving Ground involving a line release from a DC-7B aircraft where median mass diameters were about 60 micrometers (Boyle, et al., 1975).

Figures 5-12 and 5-13 show calculated normalized dosage profiles for the same source and meteorological inputs used in obtaining the deposition profiles. The effect of reflection of the smaller droplets is evidenced in both figures by the inflection of the profiles at the longer downwind distances showing sustained levels of higher

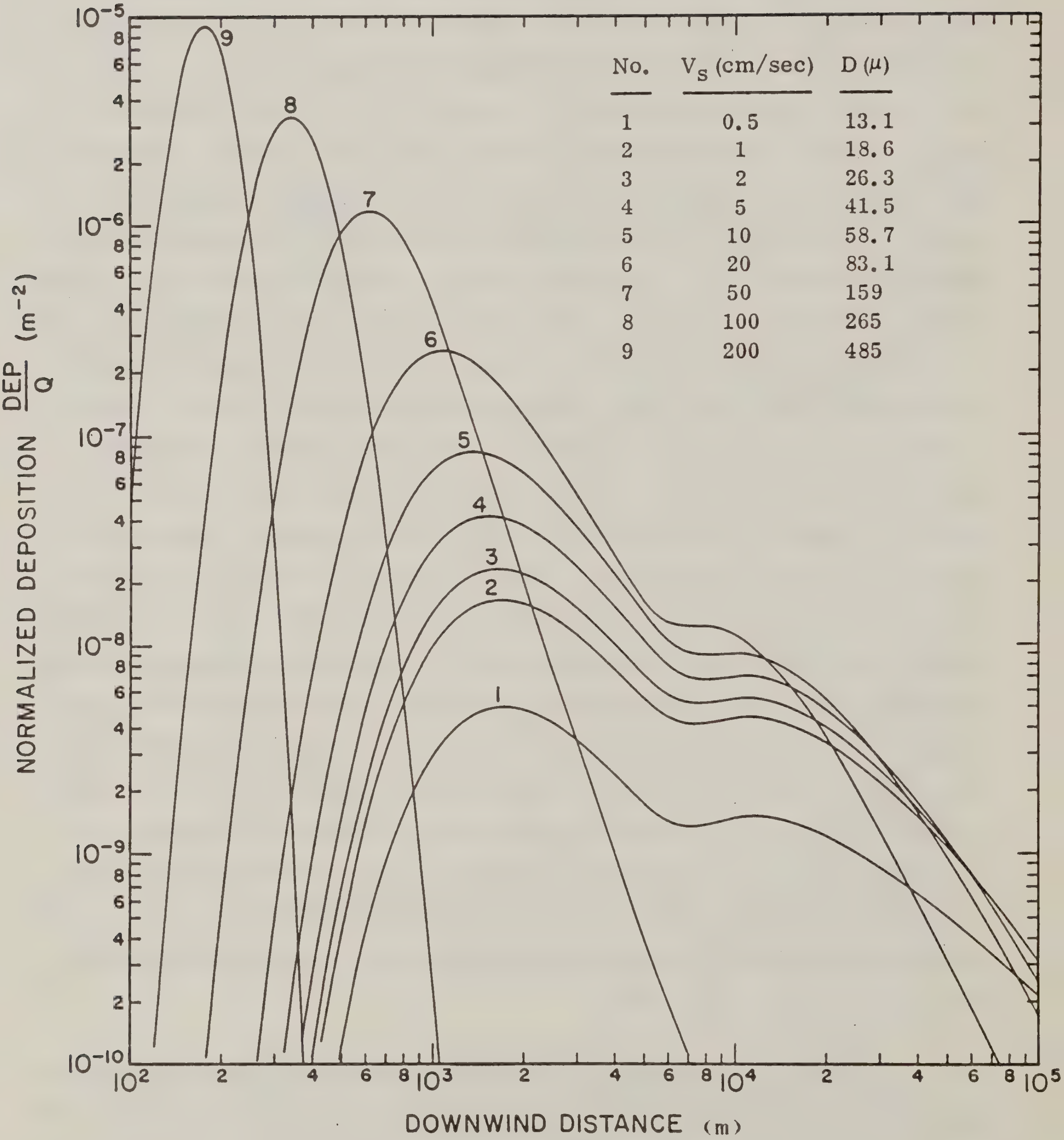

FIGURE 5-10. Normalized deposition calculated for nine settling-velocity categories using a mean wind speed $\bar{u}_R$ of 2 meters per second and a wind profile exponent p of 0.13.

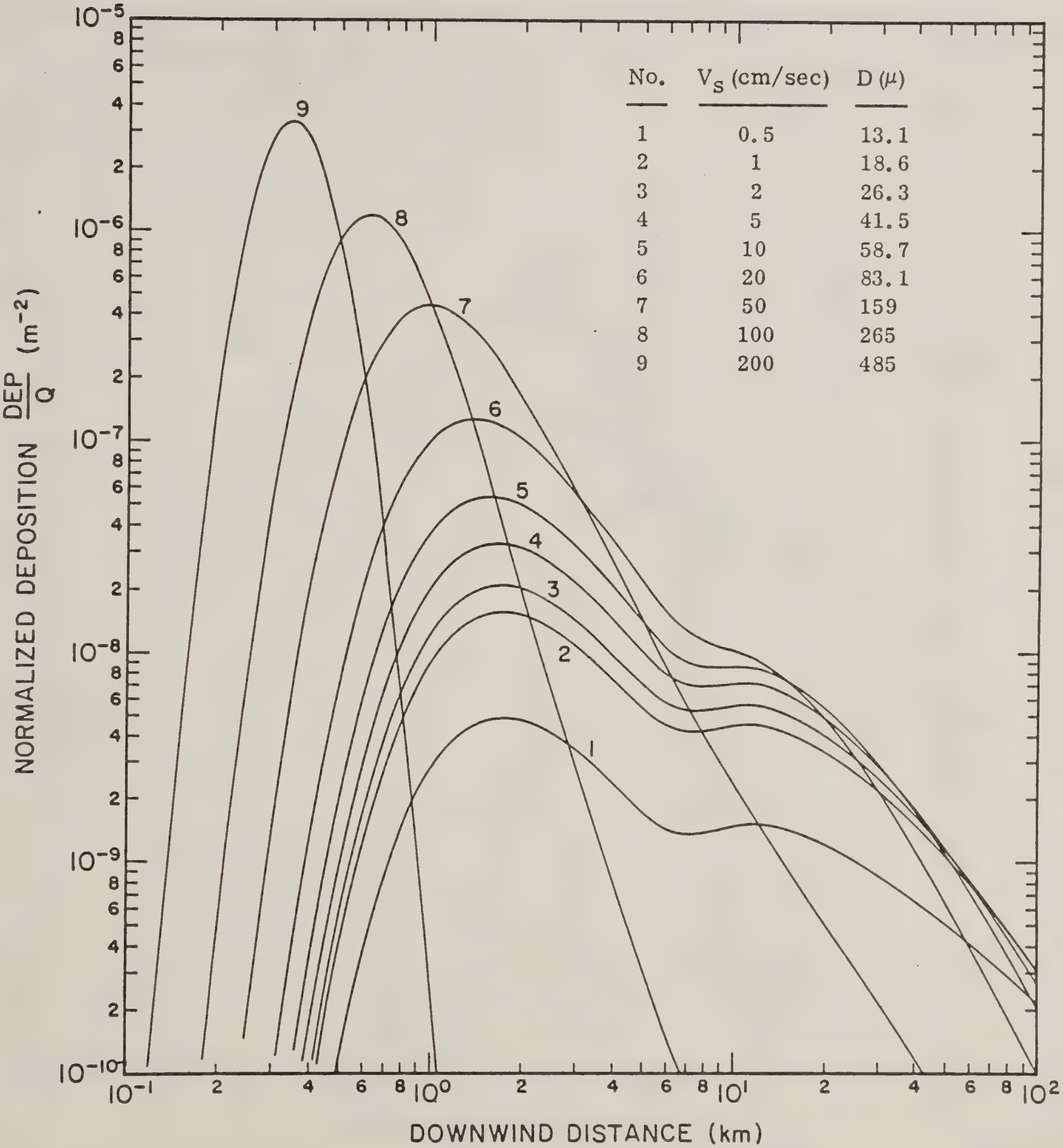

FIGURE 5-11. Normalized deposition calculated for nine settling-velocity categories using a mean wind speed $\bar{u}_R$ of 5 meters per second and a wind profile exponent p of 0.08.

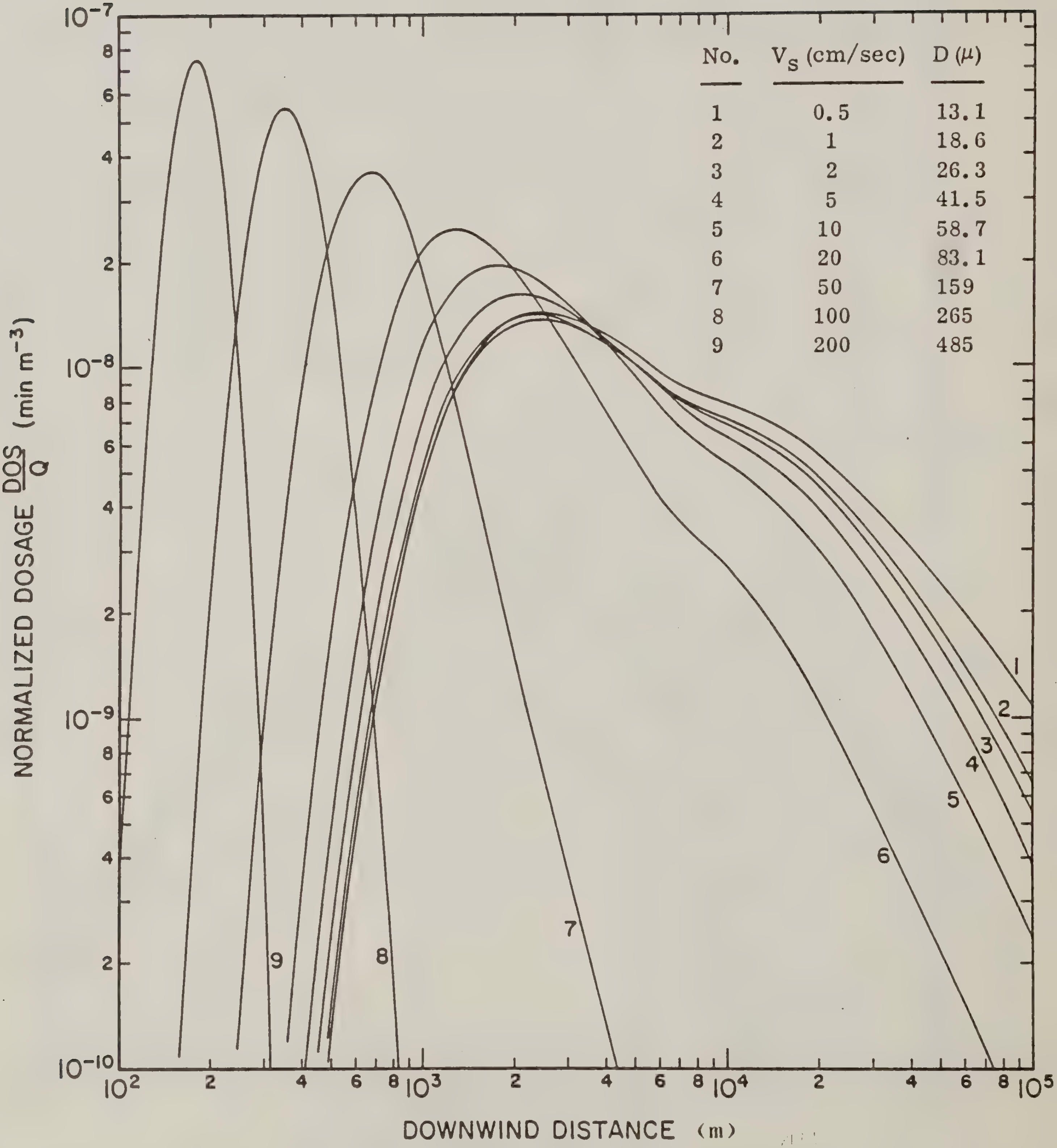

FIGURE 5-12. Normalized dosage calculated for nine settling-velocity categories using a mean wind speed $\bar{u}_R$ of 2 meters per second and a wind profile exponent p of 0.13.

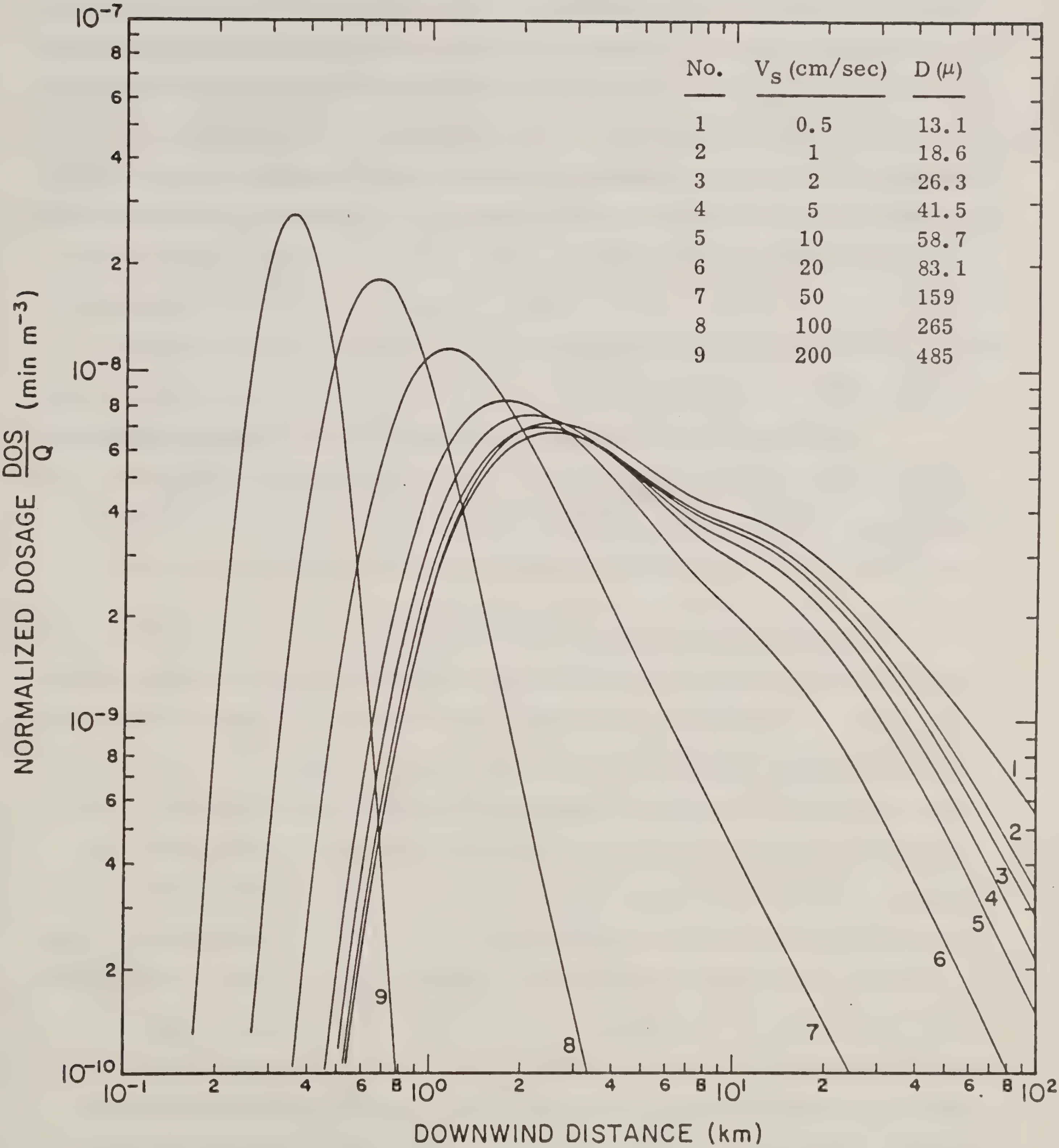

FIGURE 5-13. Normalized dosage calculated for nine settling-velocity categories using a mean wind speed $\bar{u}_R$ of 5 meters per second and a wind profile exponent p of 0.08.

dosages as droplet size decreases. The effects of increased wind speed on airborne dosages is also evident from inspection of Figures 5-12 and 5-13. As in the case of the deposition profiles, the distance to the maximum peak dosage increases with increases in wind speed for the larger drop sizes, but varies little for the smaller drop sizes. However, in contrast to the results shown in the deposition profiles, the magnitude of the maximum peak dosage decreases with increasing wind speed for all sizes of droplets because of the dependence of dosage on the speed with which the cloud passes a fixed point in space.

5.5 SUMMARY

The comparison of model and observed profiles of crosswind integrated total deposition from Trials 1 through 6 of the 70-11 Test Series indicates the DPG deposition model can be successfully used to estimate deposition downwind from aerial line sources comprised of droplets with appreciable settling velocities.

Little success was acheived in Subtest 3 of the 70-11 Test Series in containing the cloud within the sampling network at distances beyond 5 kilometers from the source. For this reason, only dosage data from Trial 5 could be used for comparison with model estimates of crosswind-integrated dosage. For Trial 5, the model estimates of crosswind-integrated total dosage compared well with the observed data obtained from a limited number of measurements from cylindrical samplers. However, the dosage model greatly underestimated observed crosswind integrated dosages for droplets with diameters less than 53 micrometers obtained from rotorod measurements using the FP tagging technique. Model underestimation in this case may be due to difficulties in the analysis of measured dosages in this size range using the FP tagging technique, but are more likely due to the use of deposition measurements to estimate the number of droplets (fraction of source strength) in this size range produced by the aircraft spray system and used in the model calculations.

The expression suggested by Murray, _et al._ (1970) for use in estimating surface deposition from rotorod dosage measurements used in conjunction with the FP tagging technique appears to produce deposition estimates which agree with the measurements of crosswind integrated deposition from Printflex card samplers for Trial 5 for small droplets. This result may be fortuitous, since such a small amount of data was available for use in the comparison. Qualitative reasoning suggests that, as droplets become smaller and behave like an aerosol, they do not tend to deposit at the surface because they fail to penetrate the microscale boundary at the air-surface interface. That is, the smaller droplets should tend to be reflected rather than be retained at the surface. An estimate of deposition based on a dosage measurement made above this boundary would tend, when used in Equation (3-11), to result in an overestimate of deposition.

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APPENDIX

PREPARATION OF THE SIMULANT/FP MIXTURE

This appendix provides a description of the procedure and recipe used by U. S. Army Dugway Proving Ground personnel in preparing the simulant/FP mixture used for a trial in which a single tank was released. The procedure was the same with a doubled recipe for a test conducted with dual tanks. The procedures described below were developed during a methodology study performed prior to Subtest 3 of the 70-11 Test Series.

Simulant/FP mixture preparation was initiated at least 25 hours before a planned trial. The mixing procedure for a single 600 liter aircraft tank required the preparation of a batch containing 950 liters of simulant mixture. This batch required preparation in two parts, 840 liters of liquid and 110 liters of liquid/solid (FP concentrate). The two parts were then combined, mixed, allowed to settle, and eventually transferred into the spray tank prior to each trial.

The 840 liters of liquid were prepared in a large 400-gallon mixing vat at Building 3008, Carr Facility, DPG. The recipe for this mixture was:

830.76 liters simulant agent
8.40 liters surface active agent (Aerosol C-61 or Arlacel 83)
0.84 liters Photo-Flo 200
5.04 kilograms Du Pont Oil Red Dye

The 110 liters of FP concentrate were prepared in two steps. First the liquid portion was prepared using the same proportions as the above mixture:

108.79 liters simulant agent
1.10 liters surface active agent (Aerosol C-61 or Arlacel 83)
0.11 liters Photo-Flo 200
0.66 kilograms Du Pont Oil Red Dye

Then the FP were added to the liquid as it was being agitated with a blender. This blending was accomplished in 4-liter batches using the following recipe:

4.0 liters liquid mixture
80.0 grams yellow FP (Lot #13)
35.2 grams green FP (H 931)

Each four liter batch of FP concentrate was added to the 840 liters of agitating liquid mixture as rapidly as transfer from the blender to the vat could be accomplished. A total of 27.5 batches of concentrate were required for the entire simulant mixture. During the combining process, the 840 liters of liquid mix were continually agitated.

After the entire 950-liter mixture was combined and thoroughly mixed, the simulant mixture was drained into a settling tray and allowed to remain undisturbed for four hours. During this period larger FP particles settled out leaving the appropriate number of FP particles per liter of liquid. At the conclusion of the four-hour settling period, the mixture was drained from the settling tray in stages to prevent turbulence within the mixture. The mixture was drained from top to bottom of the settling tray through a series of spigots arranged vertically along one end of the tray. A minimum of 730 liters was drained into a 400 gallon mixing vat whose agitator was in operation.

The simulant mixture in the mixing vat was now ready for loading into the spray tank. The mixture in this state required continuous agitation until loaded into the TMU-28/B spray tank. If agitation was interrupted for longer than two hours, the entire mixture (950 liters) preparation was repeated.

The residual mixture in the settling tray was used in the preparation of FP concentrate for subsequent mixture preparations. Laboratory analysis was

performed on the residual mixture to determine the amount of FP per liter of liquid remaining and, based on this information, the new batch of concentrate was made.

APPENDIX

III

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 2-CO-153-000-029	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) DC7B Aircraft Spray System for Large-area Insect Control		5. TYPE OF REPORT & PERIOD COVERED Data Report Oct 1974
		6. PERFORMING ORG. REPORT NUMBER DPG-DR-C980A
7. AUTHOR(s) D.G. Boyle W.T. Taylor J.W. Barry W.C. McIntyre R.K. Dumbauld C.O.Eckard--H.E. Cramer		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Dugway Proving Ground Dugway, UT 84022		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Food and Agriculture Organization of United Nations, Liaison office for North America Washington DC.		12. REPORT DATE November 1975
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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aerial spraying	Swath width	Endosulfan
DC-7B aircraft	Fuel oil	
Insecticides	Duphar	
Droplet spectra	Tsetse fly	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Dugway Proving Ground conducted 10 trials of the DC-7B aircraft aerial spray system during October 1974. Two spray formulations, were disseminated and evaluated using three flow rates. Spray droplets were sampled vertically on towers and horizontally on ground surfaces. This report presents data on deposition and impaction sampling, droplet spectra, spray mass deposit, swath width, and mathematical modeling of the spray behavior.

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Table 2-2. Revised scope of testing

PHASE		Application Rate Oz/Ac	Application Rate GPM	Number of Trials	Test Grid	SAMPLERS Position	SAMPLERS Type	SAMPLERS Number
1	Crosswind (Tower Flyby)	3 (20 mg/m^2)	25	2	ASG (300-ft tower)	Vertical	Inert Cylinder (Pipe Cleaner) Beer Can Cyl. Printflex Filterpaper	92 8 8
		5 (35 mg/m^2)	60	2		Hor. Upwind	Printflex	18
		20 (140 mg/m^2)	230	2		Hor. Downwind	Printflex	74
2[a]	Inwind	3	25	1	Downwind Grid (3-mile sq. w/3dense lines normal to wind)	Horizontal	Printflex	315
		5	60	1				
		20	230	1				
3	Crosswind Dwd Drift	5	60	1[b]	ASG[c] (15-mile downwind w/300 ft tower)	Vertical	Same as phase 1	
						Hor. Upwind	Same as phase 1 plus Rotorods from tower to 15 miles downwind Printflex	70 114

[a] In this trial, the 30-meter meteorological sampling mast will be decorated.

[b] This trial will be conducted when prefrontal winds are available as part of Phase 1.

[c] Rows 390, 678, 966, West Downwind, 523 and Hwy 101 will be used with samplers spaced at 150-foot intervals.

Twelve trials were conducted during October 1974. Acceptable data were obtained in five trials, and partial data were obtained in five trials. Spray rates ranged from an estimated 0.07 to 4.38 liters per hectare. In the four Target S trials, the flight path was approximately parallel to the wind direction (the system malfunctioned in one trial). In seven of the eight ASG trials the flight path was approximately perpendicular to the mean wind direction. Requisite data for characterizing the vertical-profile mass distribution and dissemination efficiency were obtained in only three of the eight ASG trials because of a combination of inadequate wind speeds and a system malfunction. Meteorological limitations imposed in the test design were waived by the UN FAO representative because of the limited period of aircraft availability.

The flight altitude of the aircraft during the trials was approximately 50 meters above the ground. Two types of spray carrier were used. Duphar, a trade-name solvent of low volatility, was used in Trials 1-6 and 1-7. In the remaining ten trials, No. 2 fuel oil was used. Dupont oil red dye was added to both types of spray carrier as a tracer. Deposition measurements were principally obtained by placing Printflex-cards on the ground before each trial (see Figure 2-1). Spray droplets deposited on the cards produced red stains that were counted and sized by microscopic analysis. This information was used to calculate both the drop-size distribution and the total mass of spray material deposited on each Printflex-card. A summary of trials actually conducted is contained in Table 2-3.

Table 2-3. Trials Conducted Under Revised Scope of UN Spray Trials

Trial Number	Date (1974)	Spray[a] Material	Programmed Application Rate gal/min	1/min	oz/acre	Flight Direction	Test Grid
1-1[b]	4 Oct	Fuel Oil	230	871	20	In Wind	ASG
1-1R[b,c]	8 Oct	Fuel Oil	230	871	20	In Wind	"
1-2[b]	8 Oct	Fuel Oil	230	871	20	In Wind	"
1-3[b]	15 Oct	Fuel Oil	230	871	20	In Wind	"
1-4[b]	15 Oct	Fuel Oil	25	95	2	In Wind	"
1-5	17 Oct	Fuel Oil[d]	60	227	5	Across Wind	"
1-6	17 Oct	Duphar	60	227	5	Across Wind	"
1-7	16 Oct	Duphar	25	95	2	Across Wind	"
2-1	9 Oct	Fuel Oil	230	871	20	In Wind	Target S
2-2[c]	9 Oct	Fuel Oil	60	227	5	In Wind	"
2-2R	10 Oct	Fuel Oil	60	227	5	In Wind	"
2-3	10 Oct	Fuel Oil	25	95	2	In Wind	"

[a] The spray materials were dyed with C1258 oil red dye.

[b] Requisite data on ASG sampling tower not obtained because of inadequate wind speed.

[c] Spray system malfunctioned (no data obtained)

[d] A small quantity of Endosulfan and fluorescent particles (FP) were mixed with the dyed fuel oil in this trial.

2.4 METHODS

A detailed description of the test-design concept, field test methods, data acquisition, and associated physical and chemical assessment techniques is presented in Chapter 3 and Appendix A. Methodology unique to this test is summarized below:

2.4.1 Spray Formulation and Tracer Materials

Characterization of this aerial spray system required the use of a combination of tracer materials (C1258 red dye, fluorescent particles and the chemical Endosulfan) and sampling methods.

a. C1258 red dye was used as a tracer in Number 2 fuel oil and Duphar to permit semiquantitative assessment of (1) mass deposition and droplet distribution at ground level from the release line to 5 miles downwind; and (2) the vertical distribution of the spray.

b. The system characterization was upgraded by using (1) Endosulfan to lower the mass detection limit for assessment of the dissemination efficiency of the system, and (2) fluorescent particles to permit detection of the downwind drift of the spray cloud to beyond 10 kilometers.

c. Selected physical properties of the two materials were measured to provide input parameters for mathematical modeling and safety information for spray operations.

d. The drop-stain relationship of the two materials collected on Printflex-card samplers was determined using laboratory techniques.

2.4.2 Sampling

a. Printflex-card samplers were used to measure spray deposition on the ground. The droplet size distribution was evaluated using three methods to estimate volume mean diameter, mass median diameter and deposition density for the spray patterns. Characterization of the area covered by deposition densities of interest were developed from these data.

b. A 98-meter vertical sampling tower equipped with impaction samplers was used to (1) obtain data on the mass distribution within the spray cloud from 0 to 92 meters above terrain, (2) to obtain data required to estimate the amount of material available for downwind transport or the dissemination efficiency of the system.

c. Rotorod samplers were used to collect fluorescent particles dispersed in the spray out to a distance of 10 kilometers. These data were used to characterize cloud intensity at long distances downwind and to provide empirical data for comparing model estimates.

2.4.3 Meteorological

Wind speed, wind direction, temperature gradient and the vertical components of wind direction were measured on 98- and 32-meter meterological towers. Surface observations and pilot-balloon (PIBAL) measurements were taken in the vicinity of the release line. These data were used to characterize the meteorological conditions associated with each trial and to develop input parameters for mathematical models.

2.4.4 Photographic

Mitchell cinetheodolites and 35-mm multidata fixed cameras were used to obtain data on the length of the spray release line, and the height, speed and heading of the aircraft during dissemination. These data were used in the dissemination efficiency estimates and to develop input parameters for the transport model.

2.5 RESULTS

2.5.1 Spray Formulations

a. In seven trials, the No. 2 fuel oil contained 0.49 $\pm$ 0.09 percent of C1258 red dye. In two trials the Duphar carrier contained 0.435 $\pm$ 0.05 percent of DuPont oil red (C1258) dye. In one trial, the fuel oil contained 1 percent Endosulfan, 0.5 percent C1258 dye and 1 percent fluorescent particles.

b. The selected physical properties measured for the fuel oil and Duphar used in the test are given below:

Physical Property	Fuel Oil	Duphar
Density (gm/ml) at 20° C	0.847	0.87
Flash Point ($^{\circ}$C)	38	111
Kinematic Viscosity (C_s) at 25° C	4.3	8.3
Evaporation Loss (% per hour)		
11° C	0.24	2.56×10^{-5}
24.4° C	0.21	9.78×10^{-3}

2.5.2 Chemical Analysis

a. The lower detection limit for Endosulfan using the gas chromatography method developed at DPG was 0.01 microgram per milliliter or 0.2 microgram per sample. The detection range was 0.01 to 5.0 micrograms per milliliter. The extraction efficiency for Endosulfan in n-heptane spiked with Aldrin (used as an internal standard) and 0.1 N sulfuric acid for a concentration range of 0.1 to 1.0 microgram per milliliter was characterized by the following expression:

$$y = 1.03 - 0.12\ X$$

where:

y = the reciprocal of the proportion of Endosulfan extracted (correction factor)

1.03 = intercept

X = log of Endosulfan concentration

b. The lower detection limit for C1258 dye in fuel oil using ultraviolet spectrography and Duphar was 0.3 microgram per milliliter over a nominal concentration range of 0.5 to 2.5 micrograms per milliliter. The average sensitivity of the analysis was 0.34 absorbance unit per microgram per milliliter.

2.5.3 Dissemination Efficiency Estimates

Dissemination efficiency was estimated in five fly-by trials. The estimates for Trials 1-2 and 1-3 are low because the vertical extent of the spray cloud was not contained by the sampling tower. The dissemination efficiency estimates for the Duphar trials 1-6 and 1-7 were twice as large as the good fuel oil trial (Trial 1-5). It is suspected this observation was caused by loss of fuel oil by evaporation. The estimated efficiencies are suspect, because the actual flow rates (source strength per unit length of the dissemination line) are unknown. The effective source strength and dissemination efficiencies assume the programmed flow rates to be correct but cannot be verified. However, the vertical recoveries obtained on Trials 1-5, 1-6 and 1-7 indicate the programmed flow rates of 60, 60 and 25 gallons per minute were probably correct. The dissemination efficiences, average meteorological conditions and aircraft operational parameters are summarized in Table 2-4 and 2-5.

2.5.4 Meteorological

Table 2-6 is a summary of the meteorological parameters for this test.

2.5.5 Swath Widths

A summary of the swath widths based on selected deposition density (mass) levels of 4, 12, 36, and 108 milligrams per square meter is given in Table 2-7. The width of the swath for areas receiving more than 10,000, 30,000, 90,000 and 270,000 drops per square meter with diameters less than 75 micrometers are also tabulated. These data should not be used to imply swath widths for either material or differences in the coverage for the two materials, since the programmed flow rates have not been verified and the sample size is inadequate to reflect a reliable indication of expected performance.

Table 2- 4. Operational, Estimated Dissemination Efficiency and Horizontal Recovery Data for Fly-By Trials

Trial	Aircraft Ground Speed (knots)	True Aircraft Heading (°)	Flow[a] Rate (l/min)	Spray Release Height (m)	Length Spray Line (m)	True Wind Direction (°)	Wind Speed (m/sec)	Average[b] Dissemination Efficiency (%)	Horizontal[c] Recovery (%)
1-2	216	225	871	55	7,400	130	1.1	18.5	2
1-3	216	225	871	46	7,400	170	1.2	32.0	ND
1-5	216	225	227	52	14,080	330	3.0	50.2	11
1-6	216	225	227	46	7,376	300	1.0	92.7	76
1-7	216	225	95	40	7,488	305	1.8	105.2	47

[a] The actual flow rate is unknown; the test sponsor did not submit these data to DPG.
[b] Estimates were made using sampling data collected on two sides of the vertical sampling tower. Estimates for Trials 1-1, 1-1R, and 1-4 could not be made because of inadequate sampling data and spray system malfunctions.
[c] These data are based on assumed flow rates.
ND = No data.

Table 2.5. Summary of Dissemination Characteristics Data for UN Trials

Trial	Type of Solvent	Programmed Application Rate of Spray Formulation[a]		Dye Concentration (g/ℓ)	Endosulfan Concentration (g/ℓ)	Source Strength		Recovery		Drop Spectra	
		(gal/min)	(oz/Acre)			Formulation (g/m)	Dye or Endosulfan (g/m)	Horizontal[b] (%)	Vertical (%)	VMD (μm)	NMD (μm)
1-1	Fuel Oil	230	20	c	c	110.0	c	11	d	89	37
1-2	Fuel Oil	230	20	5.0	c	110.0	0.649	2	d	56	32
2-1	Fuel Oil	230	20	c	c	110.0	c	1	d	51	31
2-2R	Fuel Oil	60	5	c	c	28.7	c	11	d	58	36
2-3	Fuel Oil	25	2	c	c	12.0	c	11	d	51	32
1-3	Fuel Oil	230	20	4.8	c	110.0	0.623	d	d	61	36
1-4	Fuel Oil	25	2	c	c	12.0	c	21	d	59	33
1-7	Duphar	25	2	4.4	c	12.3	0.0621	47	105.2	63	47
1-6	Duphar	60	5	4.3	c	29.5	0.146	76	92.7	71	46
1-5	Fuel Oil	60	5	c	8.9	28.7	0.302	11	50.1	56	33

[a] See Table 3-1

[b] Based on deposition of spray formulation

[c] No assay

[d] Wind direction invalidated vertical or horizontal recovery

Table 2-6. Summary of Meteorological Parameters

Parameter	Trial Number									
	1-1	1-2	1-3	1-4	1-5	1-6	1-7	2-1	2-2R	2-3
Date	Oct 4 1974	Oct 8 1974	Oct 15 1974	Oct 15 1974	Oct 17 1974	Oct 17 1974	Oct 16 1974	Oct 9 1974	Oct 10 1974	Oct 10 1974
Release Time (MST)	1406	1320	1254	1037	1249	0953	1434	1055	1048	1247
Sunrise-Sunset (MST)	0631-1809	0635-1803	0642-1752	0642-1752	0644-1749	0644-1749	0643-1751	0636-1801	0637-1800	0637-1800
Ground Conditions	Moist	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
Weather Conditions	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair
Cloudiness (10ths)	10	10	10	10	0	0	10	1	2	5
H_m[a] (m)	ND	ND	ND	ND	850	150	400	800	350	500
Wind Direction (deg)	Var.	Var.	Var.	Var.	330	300	305	162	315	320
$\bar{\mu}$[b] (m sec^{-1})	1.0	1.5	1.7	1.0	3.0	1.0	1.8	6.1	4.0	4.2
ΔT[c] (0.5-96m) (^oC)	-1.6	-	-2.1	-1.8	-2.4	-2.3	-2.4	-3.2	-3.6	-3.4
SR[d] (0.5-96m) (^oC sec^2 m^{-2})	-1.6	-	-.73	-1.8	-.27	-2.3	-.74	-.08	-.23	-.19
σ_A[e] {2.5} (deg)					10	5	10	ND	5	5
σ_E[f] {2.5} (deg)					10	5	10	ND	5	3
$\bar{T}$[g] (^oC)	16.7	21.0	21.9	17.6	23.0	17.7	24.5	18.9	16.6	19.4
Relative Humidity (%)	49	23	21	28	20	29	21	45	48	34

[a]Height of mixing layer.

[b]Mean wind speed.

[c]Vertical temperature gradient.

[d]Stability ratio = SR (96 m to 0.5 m) = $(T_{96}-T_{0.5})/(\bar{u})^2$.

[e]Standard deviation of wind azimuth.

[f]Standard deviation of vertical component of wind direction.

[g]Mean temperature.

Table 2-7. Summary of Swath Widths

Trial	Flow Rate (l/min)	Direction of Flight	Swath Width (m) for the Indicated Deposition Densities (mg/m^2)				Swath Width (m) for Areas Within the Pattern Receiving the Indicated Number of Droplets Having Diameters less than 73 Micrometers			
			4	12	36	108	10,000	30,000	90,000	270,000
1-1	871	In Wind	273	185	89	23	465	319	205	145
1-2	871	In Wind	176	23	0	0	521	394	203	45
1-3	871	In Wind	297	191	114	0	>1,009	726	329	187
2-1	871	In Wind	0	0	0	0	736	350	19	0
2-2R	227	In Wind	211	41	0	0	1,336	705	163	20
1-5	227	Across Wind	179	52	0	0	660	422	175	84
1-6*	227	Across Wind	1,318	290	120	14	>1,568	>1,568	478	138
1-4	95	In Wind	111	59	0	0	1,199	440	117	29
1-7*	95	Across wind	181	62	0	0	469	208	86	32
2-3	95	In Wind	89	0	0	0	437	268	142	49

*Duphar used as carrier.

2.5.6 Droplet Spectra

The volume median diameter (vmd) and number mean diameter (nmd) for each trial were estimated using the techniques described in Appendix A; the values are tabulated in Table 4-5. The vmd and nmd for the two Duphar trials (Trials 1-6 and 1-7) were 65.5 + 3.5 micrometers and 45.5 $\pm$ 2.1 micrometers, respectively. The vmd range for the eight trials using fuel oil ranged from 50 to 71 micrometers. The mean vmd was 57.1 $\pm$ 6.47 micrometers. The nmd range for the fuel oil sprays was 31 to 57 micrometers, with a mean of 36.0 $\pm$ 8.62 micrometers. The cumulative percent of mass associated with the range of droplets measured in each trial in which the programmed flow rate was 871, 227 and 95 liters per minute (230, 60 and 25 gallons per minute) are given in Figures 2-2, 2-3, and 2-4, respectively. The cumulative numerical distribution for the range of droplet sizes measured in trials with flow rates of 871, 227 and 95 liters per minute are given in Figures 2-5, 2-6, and 2-7. These data were used to generate the droplet data inputs, i.e. the settling velocity (V_{si}) and the fraction of mass (f_i) for each mean droplet diameter, Table 5-2.

2.5.7 Mathematical Model of DC-7B Spray System

The data obtained from five acceptable trials (Trials 1-5, 1-6, 1-7, 2-2R and 2-3) were used to develop the input parameters for a mathematical deposition model by H.E. Cramer, K.R. Dumbauld, et al. The model was used to estimate the axial deposition densities of the spray pattern as a function of downwind distance. The axial deposition densities right and left of the flight path were also estimated. The model and actual values were comparable, indicating the model is valid. In this analysis, the estimates of axial deposition density were restricted to a downwind distance of 10 kilometers.[1] No attempt was made to estimate deposition density directly below the flight path. Such estimates would require detailed knowledge of the trailing vortices and the interaction of the vortex system with the spray droplets and the atmosphere during the first 60 to 100 seconds after discharge of the spray. The general effect of wingtip vortices on the shape of the spray cloud was also investigated. The lateral source dimension of the spray cloud σ_{yo} was estimated as 20 meters (corresponding to a cloud diameter of 84 meters or three wingspans of the aircraft).

The results achieved with this model strongly imply that the downwind drift of spray clouds can be estimated using a modified form of the generalized concentration-dosage model for elevated line-source releases available at DPG. The model development and results are detailed in Chapter 5.

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[1]Evidence of spray cloud drift 10 kilometers downwind of the release line was verified by FPs collected on rotorod samples in Trial 1-5. These data are contained in Appendix B.

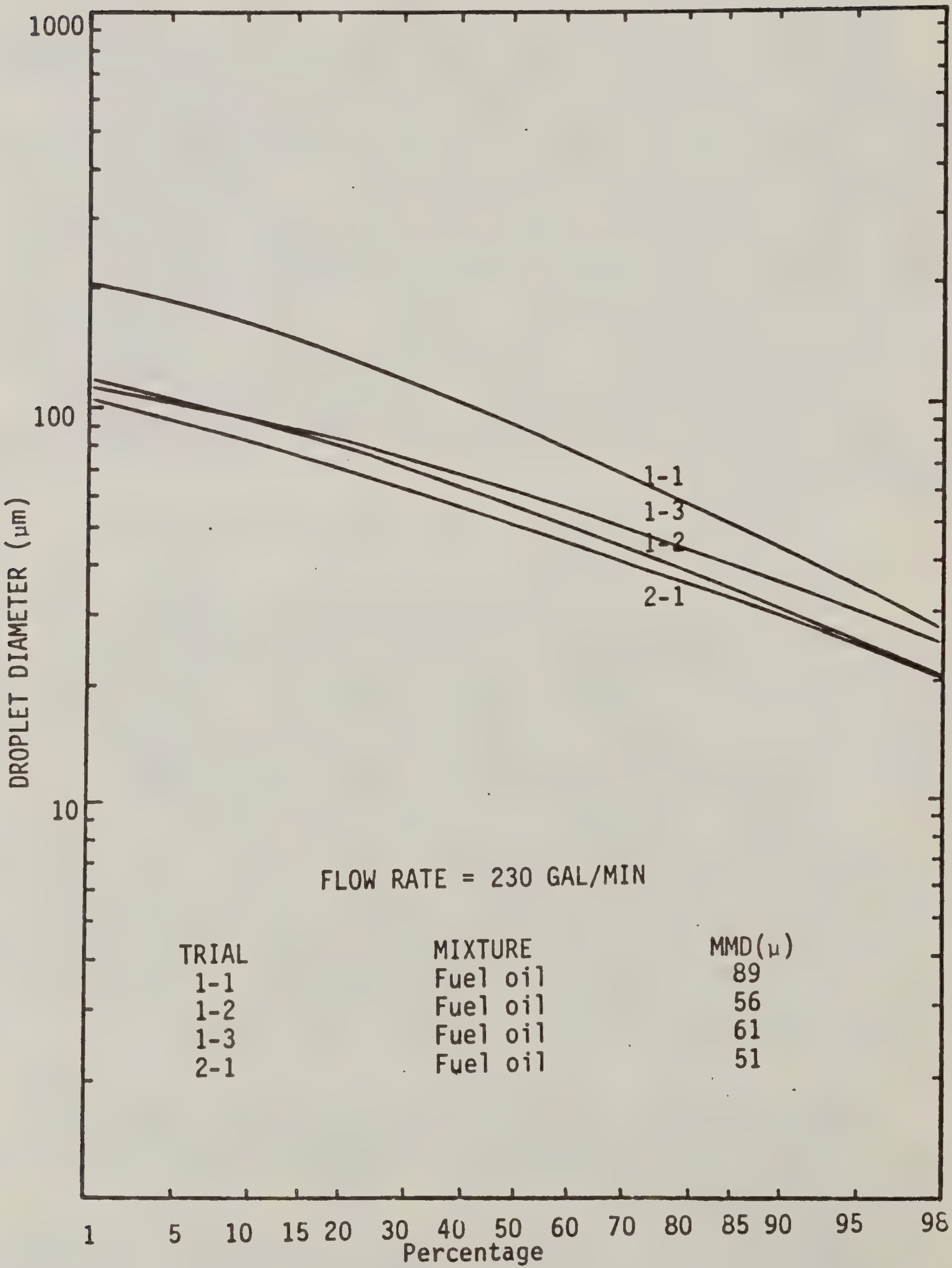


Figure 2-2 Cumulative Mass Distribution of Droplets as a function of Droplet-Diameter

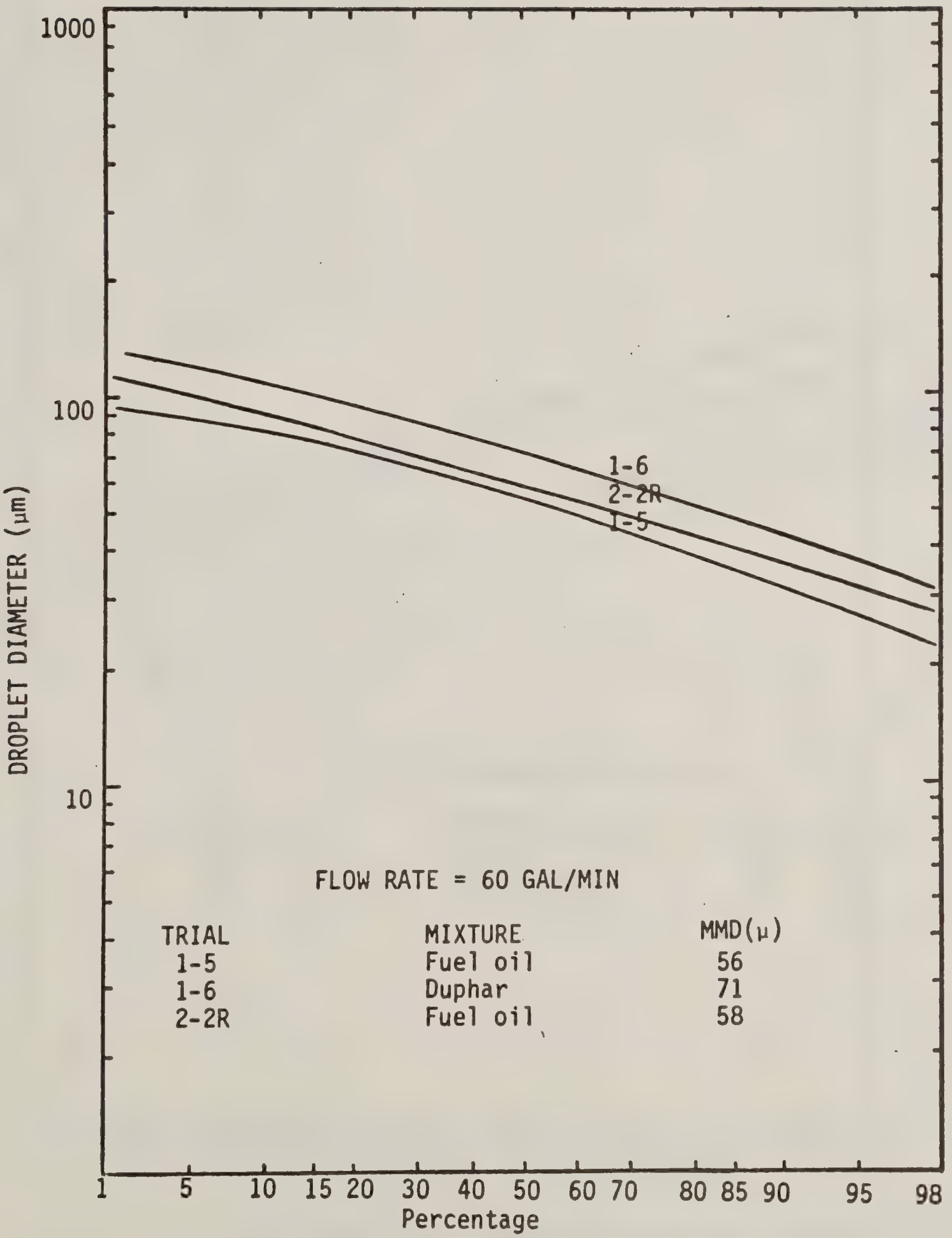


Figure 2-3 Cumulative Mass Distribution of Droplets as a function of Droplet-Diameter

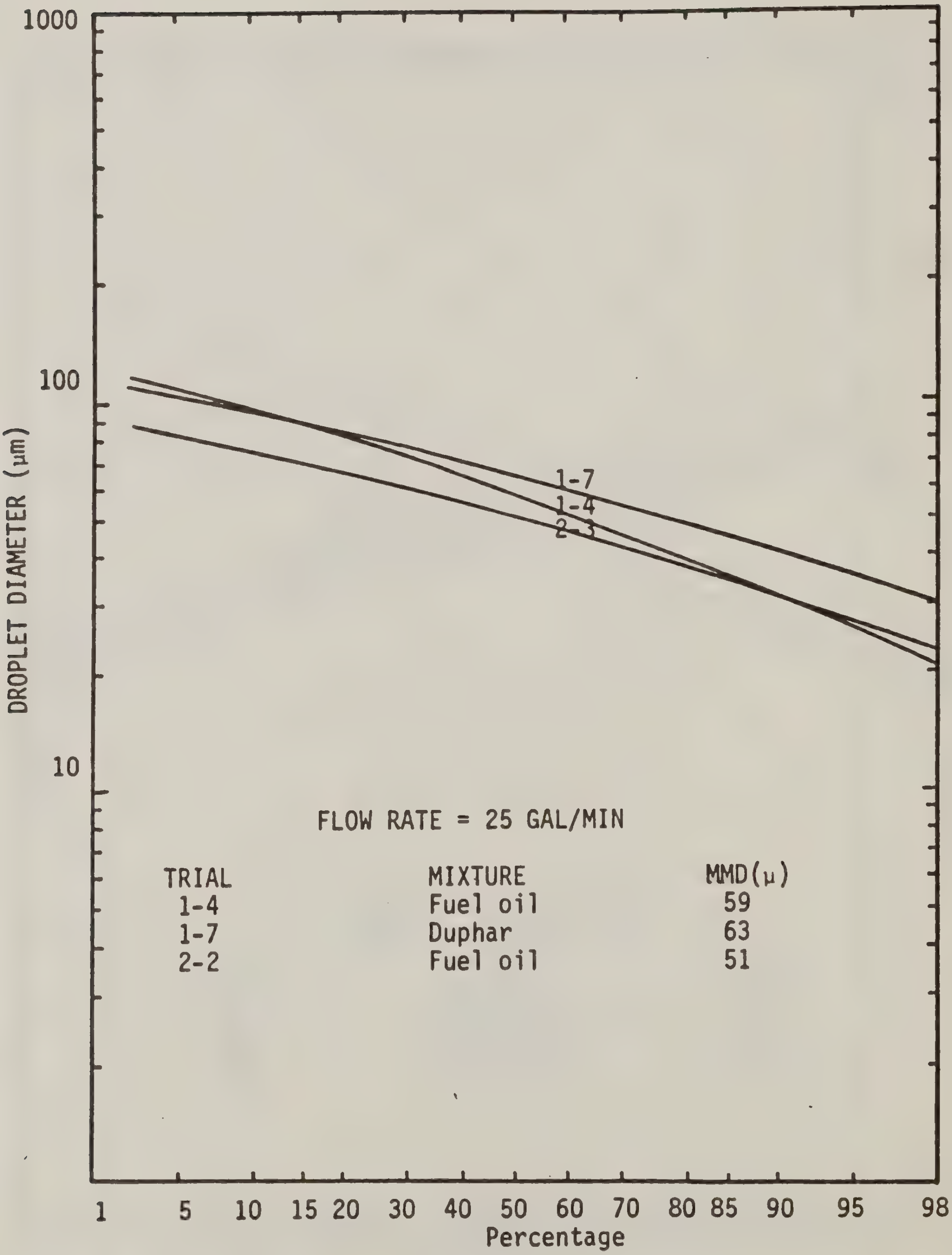


Figure 2-4 Cumulative Mass Distribution of Droplets as a function of Droplet-Diameter

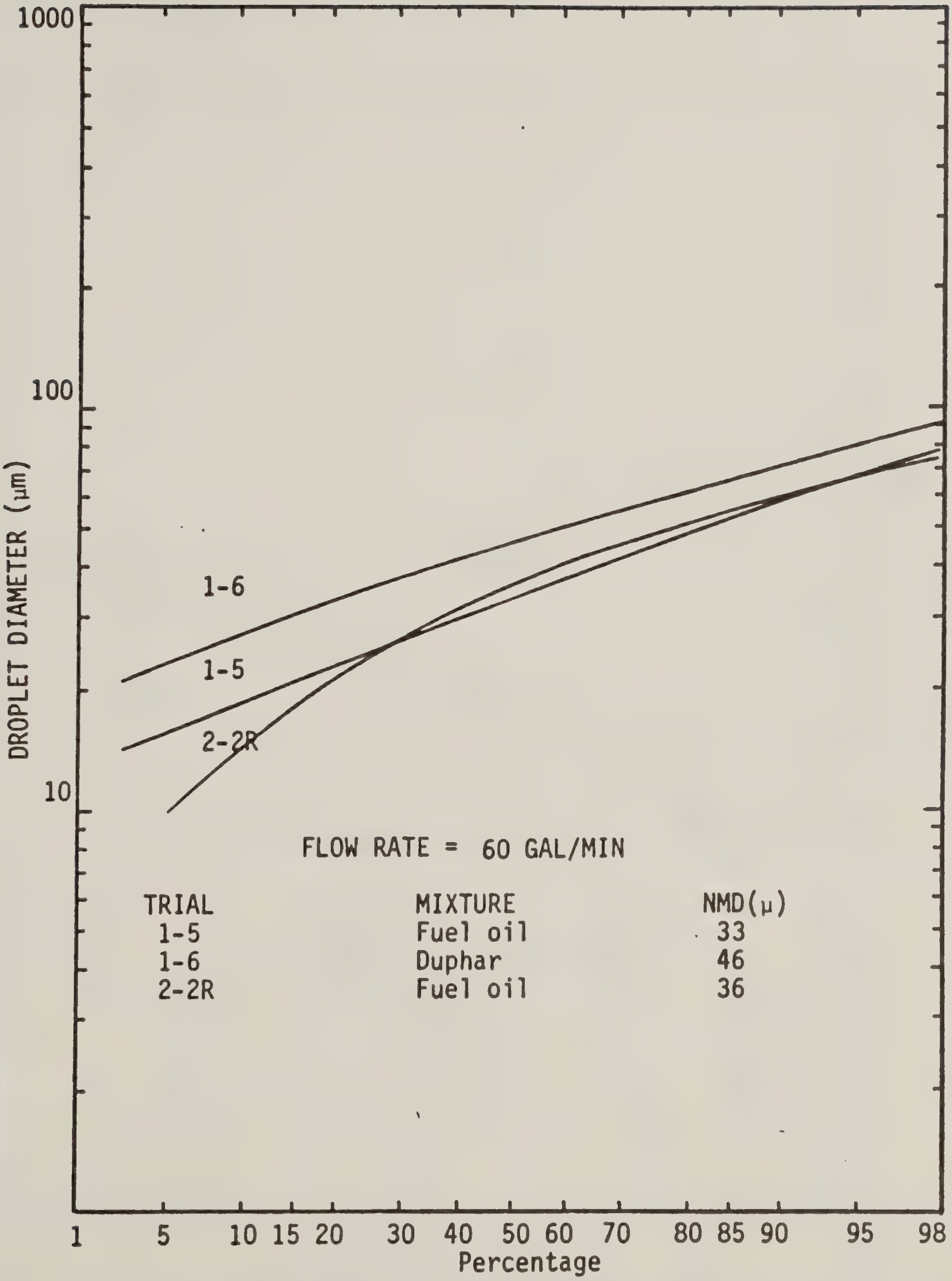


Figure 2-6 Cumulative Numerical Distribution of Droplets as a function of Droplet Diameter.

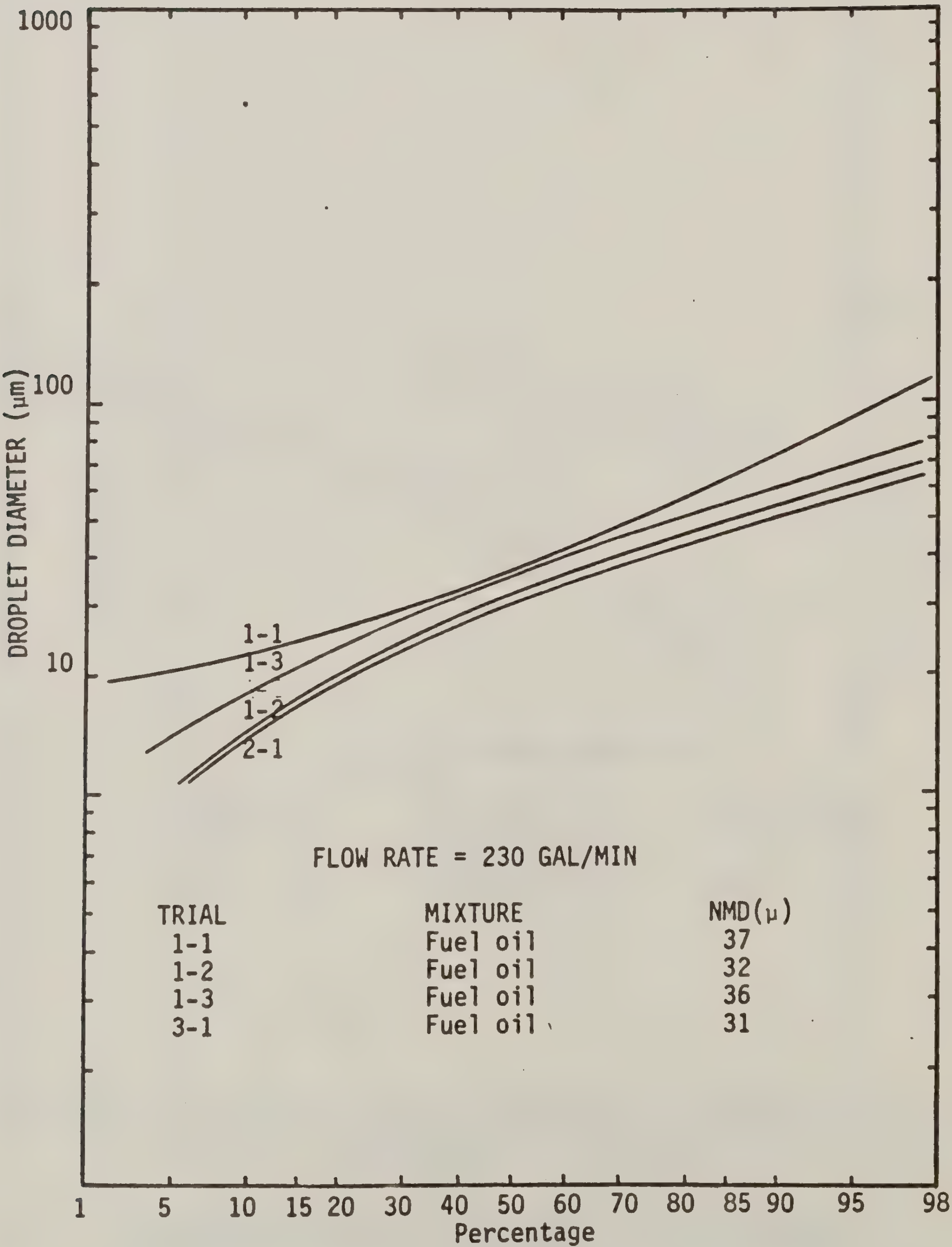


Figure 2-5 Cumulative Numerical Distribution of Droplets as a function of Droplet Diameter.

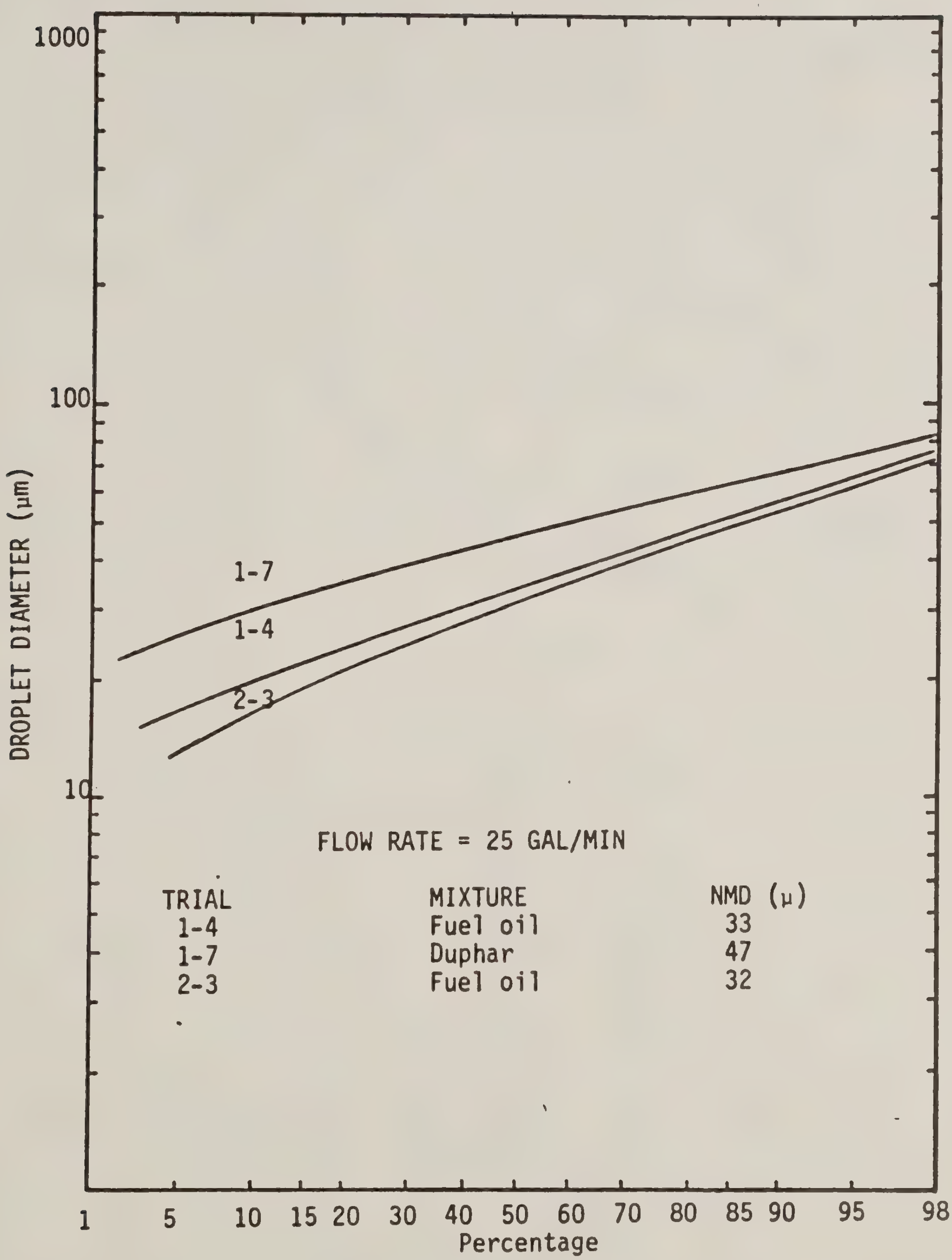
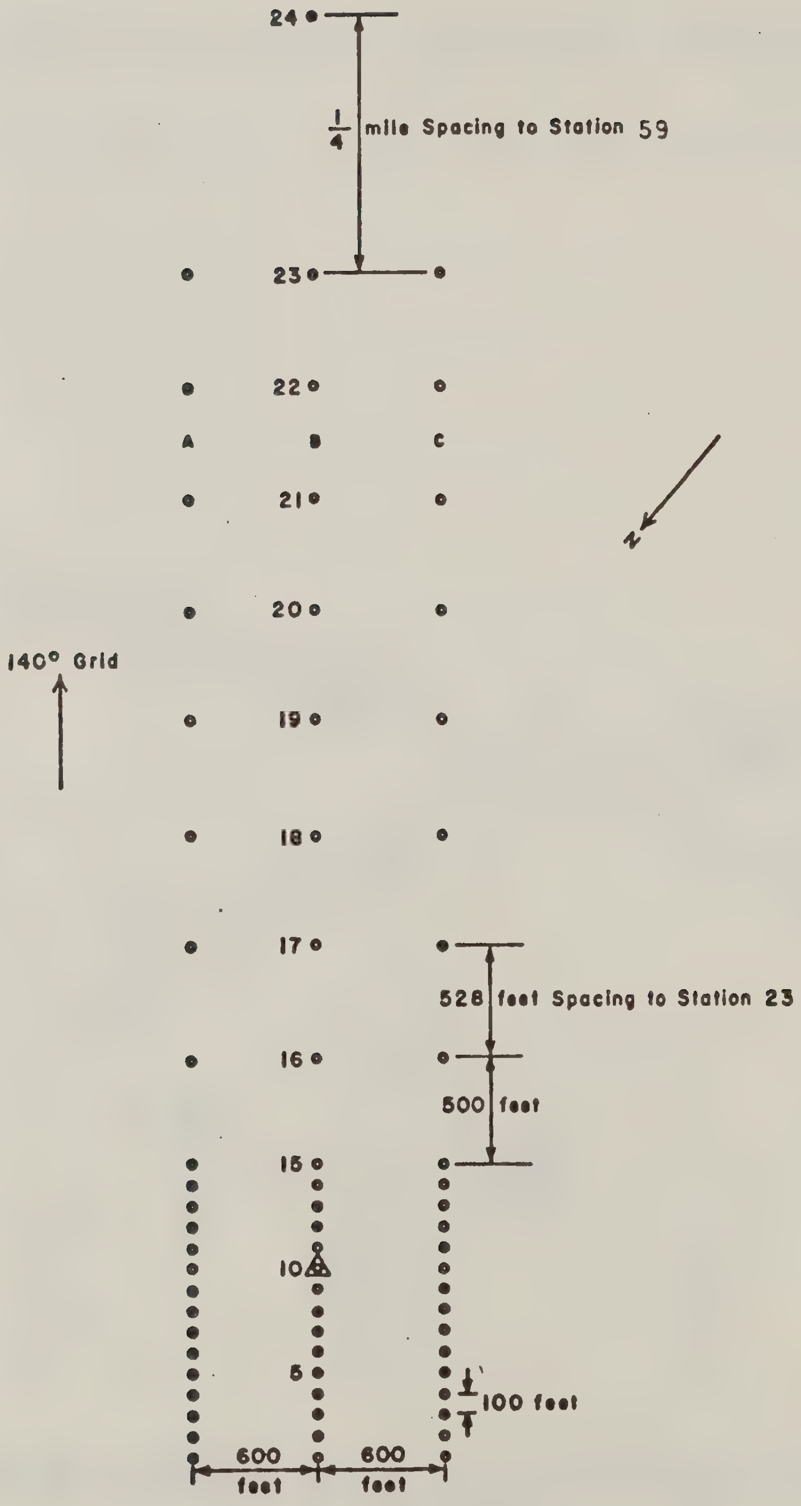
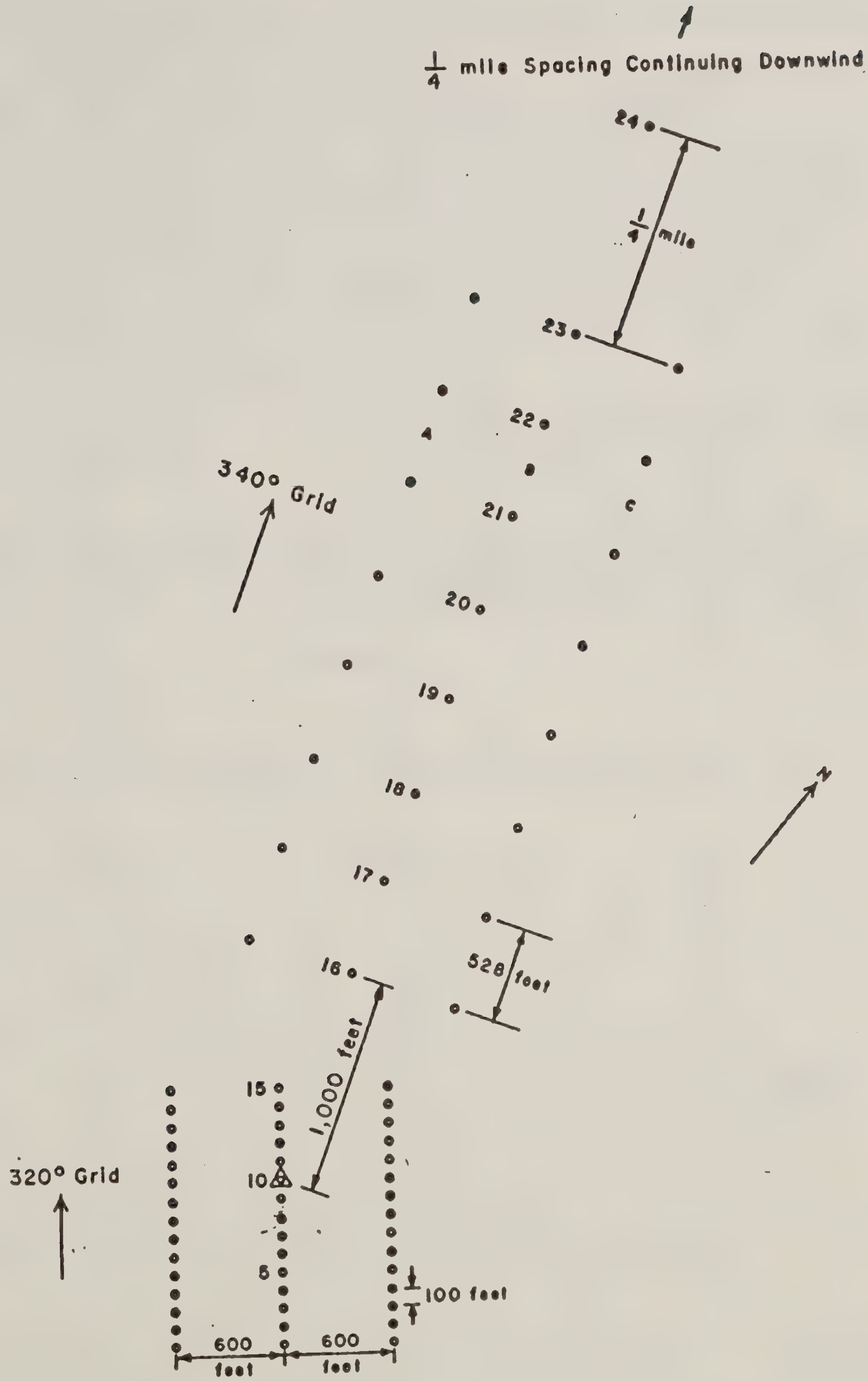


Figure 2-7 Cumulative Numerical Distribution of Droplets as a function of Droplet Diameter.



△ 98m Tower

Figure 4-1. Grid used for NW winds, Trials 1-1, 1-3, 1-5, 1-6, 1-7



△ 98m Tower

Figure 4-2. Grid used for SE winds, Trials 1-2, 1-4

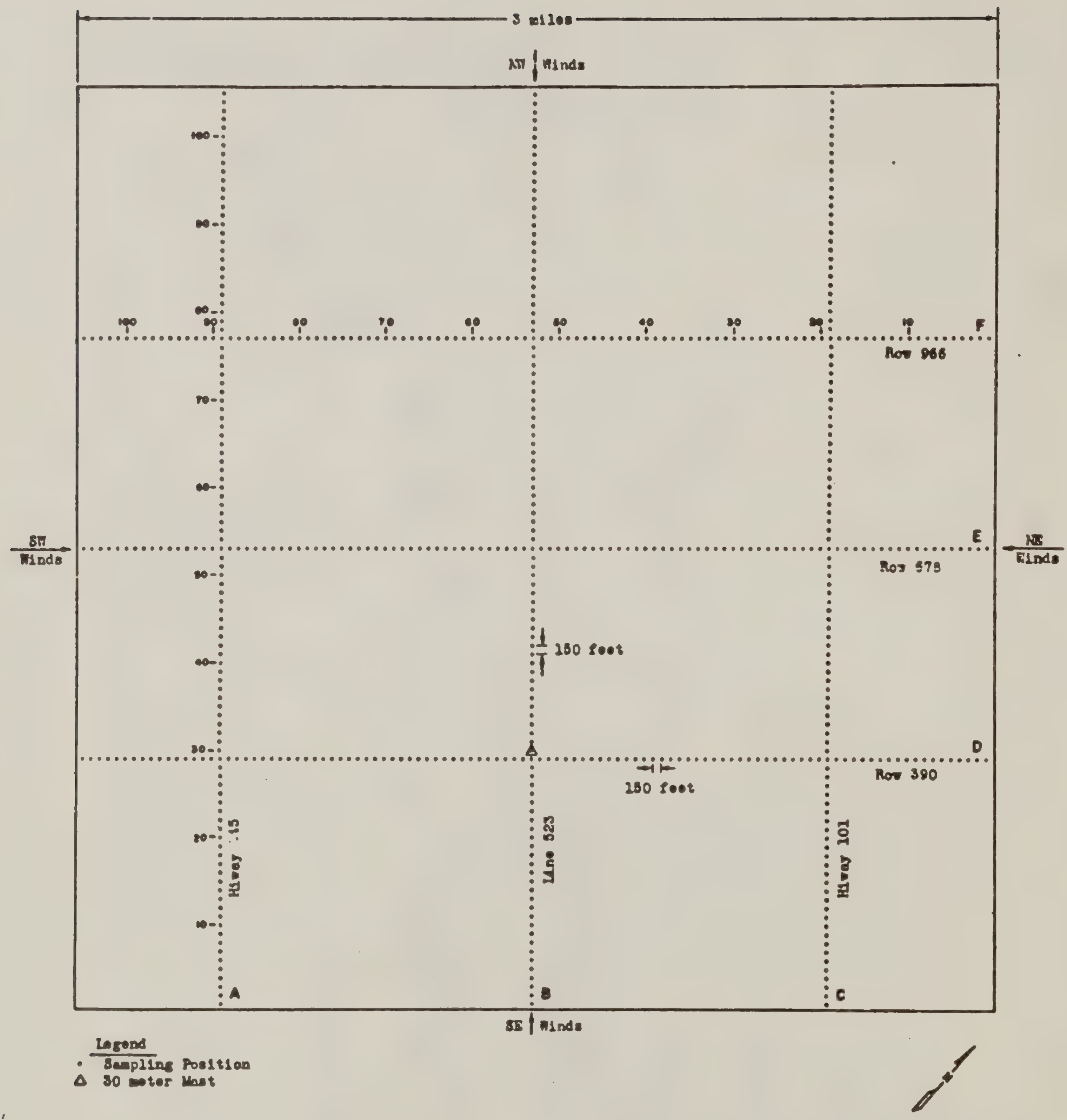


Figure 4-3. Grid used for Trials 2-1, 2-2R, 2-3

from the three sampling lines. In Trial 1-6, only two sampling lines were available for averaging because of problems in sampling. Table 4-1 gives swath widths based on mass.

4.1.2 Swath Width from Particle Size/Density Analysis

The ground deposition densities in droplets per square meter for particle sizes of <21μm, <38μm, <55μm, and <73μm versus downwind distance were plotted for each trial. An average swath width of each trial for particle sizes less than 73μm and for densities of 10,000, 30,000, 90,000 and 270,000 drops per square meter are given in Table 4-2.

Table 4-1. Swath Width Based on Mass

Trial	Programmed Application Rate (gal/min-ℓ/min)	Swath Width (feet-meter)			
		4 mg/m^2	12 mg/m^2	36 mg/m^2	108 mg/m^2
1-1	230-871	897- 273	607-185	298- 89	77-23
1-2	230-871	577- 176	77- 23	--a--	--a--
2-1	230-871	--a--	--a--	--a--	--a--
1-3	230-871	973- 297	627-191	373-114	--a--
2-2R	60-227	692- 211	133- 41	--a--	--a--
1-6	60-227	4325-1318	950-290	395-120	45-14
1-5	60-227	587- 179	170- 52	--a--	--a--
2-3	25- 95	292- 89	--a--	--a--	--a--
1-7	25- 95	593- 181	203- 62	--a--	--a--
1-4	25- 95	363- 111	193- 59	--a--	--a--

[a]deposition density (mass) in column heading not achieved.

Table 4.2 Swath Width Based on Droplet Deposition Density of Particles Less than 73μm

Trial	Programmed Application Rate (gal/min)	Swath Width (feet-meters)			
		10,000 droplets[b]	30,000 droplets	90,000 droplets	270,000 droplets
1-1	230	1525- 465	1047- 319	673- 205	476-I45
1-2	230	1709- 521	1293- 394	666- 203	148- 45
2-1	230	2415- 736	1148- 350	62- 19	--a--
1-3	230	>3310->1009	>2382-> 726	>1079->329	614-187
2-2R	60	4383- 1336	2313- 705	535- 163	66- 20
1-6	60	>5144->1568	>5144->1568	1568- 478	453-138
1-5	60	2165- 660	1385- 422	574- 175	276- 84
2-3	25	I434- 437	879- 268	466- 142	161- 49
1-7	25	1539- 469	682- 208	282- 86	105- 32
1-4	25	3934- 1199	1444- 440	384- 177	95- 29

[a] Droplet deposition density in column heading not achieved.

[b] per square meter

4.2 HORIZONTAL RECOVERIES

4.2.1 Horizontal Recoveries by Mass

Horizontal recoveries in terms of mass density in milligrams per square meter over the sampled portion of the grid are presented as contour diagrams in Figures 4-4 through 4-13.

4.2.2 Horizontal Recoveries by Density

The ground deposition densities in droplets per square meter for particle sizes of <21μm, <38μm, <55μm, and <73μm versus downwind distance are presented in Figures 4-14 through 4-20. Isopleths of droplet densities for all droplets less than 73μm are shown in Figures 4-21 through 4-30.

4.2.3 Total Grid Recovery

Table 4-3 presents estimates of the spray material recovered on the horizontal grid. Estimates are given for nine trials. The data from Trial 1-3 were invalidated by the wind direction. A continuation or completion of the test as originally detailed in the plan of test would have provided sufficient data for more definitive estimates of horizontal grid recovery.

Table 4-3. Estimated Percent of Material Recovered on the Horizontal Sampling Grid

Trial	1-1	1-2	2-1	2-2R	2-3	1-3	1-4	1-7	1-6	1-5
Horizontal Recovery (%)	11	2	1	11	11	(a)	21	47	76	11

(a) Wind direction invalidated horizontal recovery.

4.2.4 Horizontal Efficiency

Horizontal efficiency is the percentage of material released from the disseminator and recovered as deposition on the ground.

The technique used in computing horizontal efficiency is very similar to that used in computing vertical efficiency. However, with a significant mass consisting of small drops (<70μm), there is a very large downwind distance associated with deposition. Consequently a very large sampling grid is required, and meteorological conditions should be uniform over an extended period. Since very small particles

(continued on page 93)

(<10μm) are assumed to behave as a gas, the particles are not deposited on the ground in the release area but are rendered ineffectual in the atmosphere by dilution and the physical phenomena of nature. For these reasons, it is very unlikely that a complete accountability of material released (mass balance) can be obtained on the horizontal sampling grids used for these trials. Additional trial data might have permitted a more valid estimate of mass accountability and with a satisfactory model, off-grid quantities could have been obtained to establish a mass balance of material.

The grids for these trials are shown in Figures 4-1, 4-2 and 4-3. At each sampling point, a Printflex card was placed (horizontal) on the ground for deposition sampling. The sampling area of the Printflex card was 308 square centimeters. Each Printflex card was assigned an area of responsibility (a horizontal area assumed to have the same deposition density as the Printflex card).

In this test, the grid can be generally described as three parallel lines. The area of responsibility for each Printflex card was a rectangle. The length (L) is calculated by the following expression:

$$\frac{d_{i+1}-d_{i-1}}{2} = l_i$$

where d is distance measured along the parallel sampling lines, i is the sequentially numbered station, and width is 1 meter. The choice of width is arbitrary as long as the release length and width of the rectangle are identical. The area dosage products are summed over the length of the line, and estimates made of the mass of material accounted for by the sampling network.

4.3 VERTICAL RECOVERIES

4.3.1 Efficiency Estimates from a Single Vertical Tower

The following describes a technique for estimating the efficiency of a continuous generator when employed in a long line release of material using a vertical array of samplers on a single tower.

4.3.2 Mathematical Development of Model

Consider an infinitely small cube of cloud with a concentration of C grams per unit volume, having dimensions dx, dy, and dz. The quantity of materials dq in the cube is

$$dq = C\,dx\,dy\,dz \qquad (1)$$

Alternately, consider a fixed vertical plane at an arbitrary downwind distance x_1 and normal to the wind vector. The amount of material passing through an area element (dy, dz) of the plane in time dt is

$$dq = u_{(y,t,z)} \, C_{(y,t,z)} \, dydtdz \qquad (2)$$

where u is the transport wind speed.

The total amount of material is

$$q = \iiint_{zty} u_{(y,t,z)} \, C_{(y,t,z)} \, dydtdz \qquad (3)$$

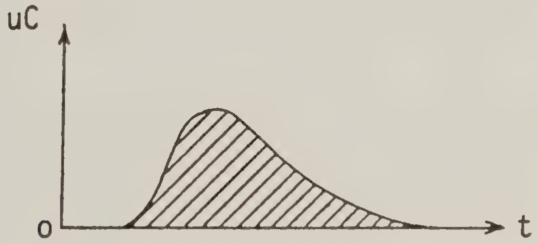
If C and u are both independent of y, then over a specified cross wind strip $-L/2 \leq y \leq L/2$, the total amount of material is

$$q = \iint_{zt} u_{(t,z)} \, C_{(t,z)} \int_{-L/2}^{L/2} dydtdz$$

where L is a specified length of release line

$$q = L \iint u_{(t,z)} \, C_{(t,z)} \, dtdz \qquad (4)$$

In the field operation, the sampling period encompasses the entire passage time of a cloud. The total dosage collected by the



Thus, the total dosage at height z is

$$D_{(z)} = \int_0^t u_{(t,z)} \, C_{(t,z)} \, dt \qquad (5)$$

assuming that the sampling device is operated long enough to sample the entire cloud.

Substituting Equation 5 into Equation 4 gives

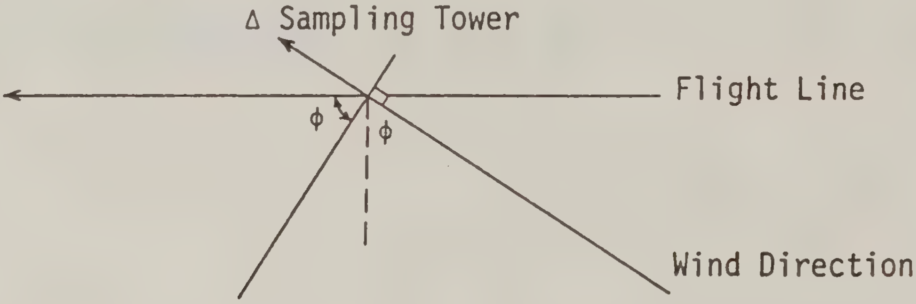
$$q = L \int_0^\infty D_{(z)} \, dz \qquad (6)$$

The output or effective line source strength is represented by the summation

$$q = L\sum_{i=1}^{n} D_i \Delta h_i \tag{7}$$

where i indicates the i-th sampling height and Δh_i is the height interval assigned to a sampling station at height i.

If the flight path is not normal to the transport wind direction, the flux density of the material is increased as it travels past the sampling tower. This is illustrated below:



where ϕ is the angular deviation of the flight line from normal to the wind direction. It is assumed that wind direction is constant over the entire height range.

The appropriate correction is achieved by rewriting Equation 1 as

$$q = (L \sum_{i=1}^{n} D_i \Delta h_i) \cos \phi \tag{8}$$

The input source strength or amount of material disseminated Q is determined by

$$Q = rL$$

where r is the rate of dissemination and L is a dissemination length which must be the same as used in q.

Any system of consistent units may be used. In this test, the units were

$$q \text{ (grams)} = L\text{(meters)}\ D\text{(grams/meter}^2\text{)}\ h\text{(meters)}$$

$$Q \text{ (grams)} = r\text{(g/m)}\ L\text{(m)}$$

Efficiency (E) is then determined by dividing the output value obtained from Equation 8 by the input source factor, Equation 9 and multiplying by 100. Thus

$$E = 100\ q/Q$$

The above technique assumes the following conditions:

a. The entire vertical dimension of the cloud is contained in the vertical sampling array.

b. The dissemination line is long enough and placed so that no edge effects exist.

c. The rate of release is uniform and known for the portion of cloud sampled.

Lack of the first two conditions will result in underestimates of efficiency. If the third condition is not met, then the variability of efficiency is increased, and a valid estimate of efficiency can be made only from a large number of trials with selected portions of release line sampled.

4.3.3 Method for Estimating Source Strength and Efficiency

1. Estimate q, the amount of material accounted for by the vertical sampling array:

a. Transform the sampler recoveries at each level to D_i values. The sampling on the vertical tower was accomplished using pipe cleaners with a sampling area of 4.5403 square centimeters per pipe cleaner. Five samplers were set up at each level. The dye from the five samplers was extracted with 15 milliliters of isopropyl alcohol and the resulting sample assayed by the spectrophotometric method. The Endosulfan from the pipe-cleaner samplers was extracted into 10 milliliters of heptane and the resulting sample assayed with the gas chromatograph. The laboratory reported the concentration values in gamma per milliliter. The dimensional model for converting to grams per square meter is

$$\frac{(\gamma/ml)\ (ml)\ (g/\gamma)}{(cm^2)\ (m^2/cm^2)} = g/m^2 \text{ of dye or Endosulfan}$$

The conversion constants of 6.607×10^{-3} or 4.405×10^{-3} for dye and Endosulfan, respectively, multiplied by the laboratory value in γ/ml yield D_i in g/m^2.

b. Assign an area of responsibility to each D_i value. The length factor (L) can be arbitrarily chosen as the length of release line or another distance of choice; for convenience, L is usually chosen as 1 meter. The length factor remains the same for all sampling heights (h). The value of Δh_i is usually $(h_{i+1} - h_{i-1})/2$. A modification is made for sample nearest the ground where

$$\Delta h_1 = h_1 + (h_2 - h_1)/2$$

The area of responsibility for each Di is $(L\Delta h_i)$

c. Obtain the total dosage-area products at each level

$D_i\ (L\Delta h_i)$ = amount in grams

d. Sum the total dosage area products

$$\sum_{i=1}^{n} Di(L\Delta h_i)$$

e. Multiply $\sum_{i=1}^{n}$ Di $(L\Delta h_i)$ by the cosine of the angular deviation of the dissemination line from normal to the wind direction. This gives the output or effective line-source strength q in grams.

$$q = L \cos \phi \sum_{i=1}^{n} D_i \Delta h_i$$

where q is the amount of material accounted for by vertical sampling array.

L is length factor

ϕ is angular deviation of dissemination line from normal to wind direction

D_i is dosage at i-th tower station

h_i is height interval assigned to each i-th tower station

2. Estimate Q input source strength (total amount of material disseminated):

a. Transform the rate in gallons per minute into grams per meter. The information for this conversion is taken from test officer's report, pilot's data sheet, photographic data reduction and the laboratory analysis of the bulk material. The dimensional model for converting to a rate (r) in grams per meter is

$$r = \frac{(\text{gal/min})\ (\text{g}/\ell)\ (\ell/\text{gal})}{(\text{mi/hr})\ (\text{hr/min})\ (\text{m/mi})} = \text{g/m}$$

The conversion constant of 1.411×10^{-1} simplifies the above to

$$\frac{(\text{gal/min})\ (\text{g}/\ell)\ 1.411 \times 10^{-1}}{(\text{mi/hr})} = \text{g/m}$$

b. Account for length of line to be sampled. This length L should be the same as that used previously, paragraph 4.3.3.1.b.

$$Q = rL$$

where Q is input source strength (total material disseminated)

r is rate in grams per meter

L is length in meters

3. Determine efficiency: divide the output line-source strength q by the input line-source strength Q and multiply by 100.

$$E = 100\ (q/Q)$$

4.3.4 Vertical Array Estimate of Efficiencies

These trials were conducted in open, flat terrain. The sampling tower is 98 meters high. Samplers were five pipe cleaners placed at each of 46 positions. The positions were at 2-meter intervals from 2 meters to 92 meters above the ground. Two arrays were set up, one on the NE corner of the tower and a second on the SW corner of the tower. Meteorological sensors were placed 2, 16, 32, 64 and 96 meters above the ground.

The material collected on the pipe cleaners asseyed by extracting the Dupont oil red dye in Trials 1-2, 1-3, 1-6, 1-7 and the Endosulfan in Trial 1-5. The concentration of Dupont oil red dye was measured by a spectrophotometer and the concentration of Endosulfan by a gas chromatograph. The chemical assay is covered in detail in Chapter 3.

Each trial is covered separately, with usefulness and limitations cited pertaining to that trial. For each trial, a vertical profile was plotted (Figures 4-31 to 4-35) and the efficiency was calculated (Tables 4-4 to 4-8). These limitations are mainly the result of conducting trials in marginal or no wind conditions. More reliable and accurate results could be expected under an organized wind condition.

4.3.5 Comments on Vertical Efficiency Trials

The UN-FAO representative (Midair Inc) did not provide definitive flow-rate information; therefore, nominal spray system setting estimates were assumed for all trial analyses.

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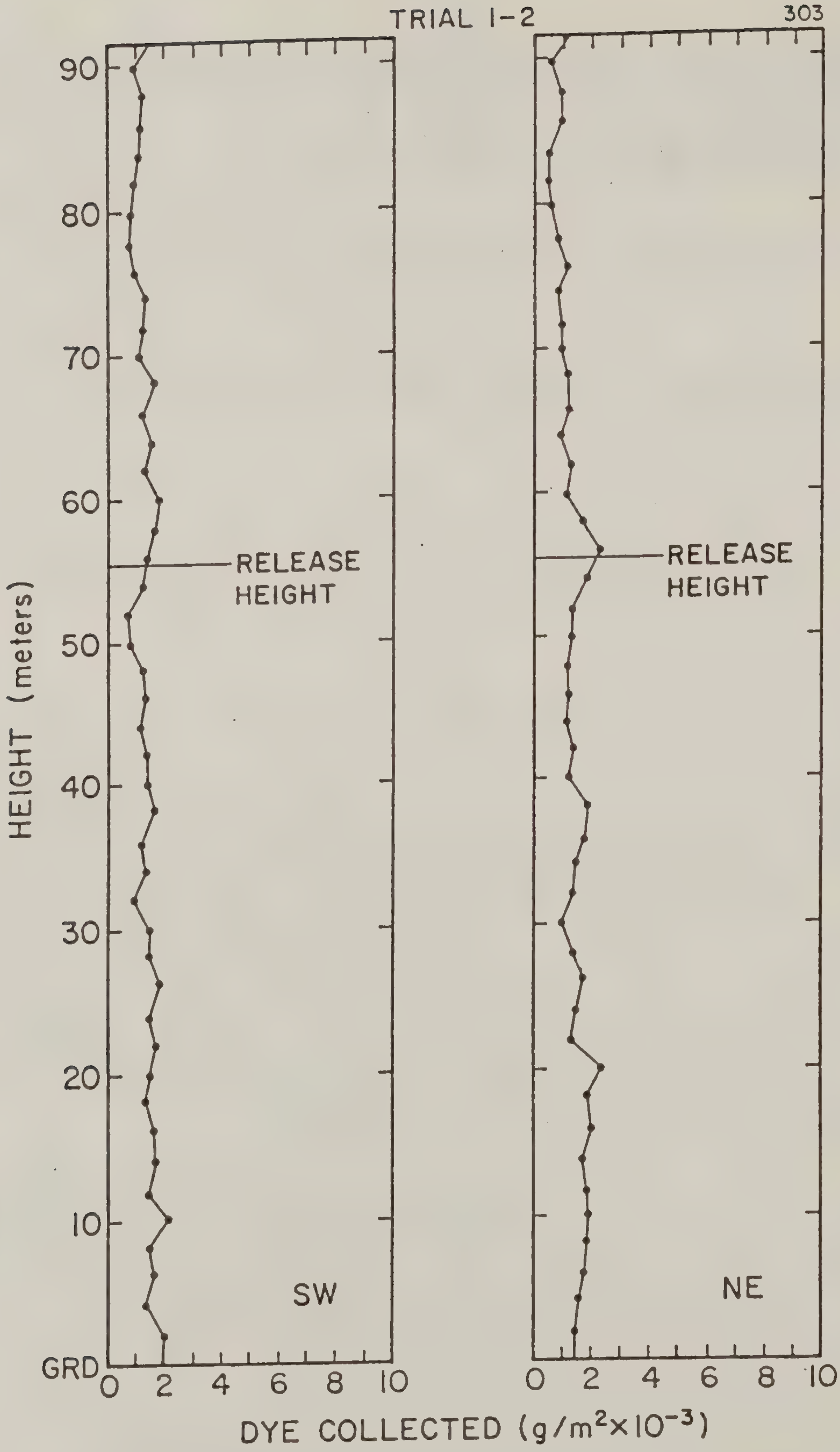

Figure 4-31. Vertical Profile of Dye Collected in Trial 1-2 from Ground Level to 90 Meters

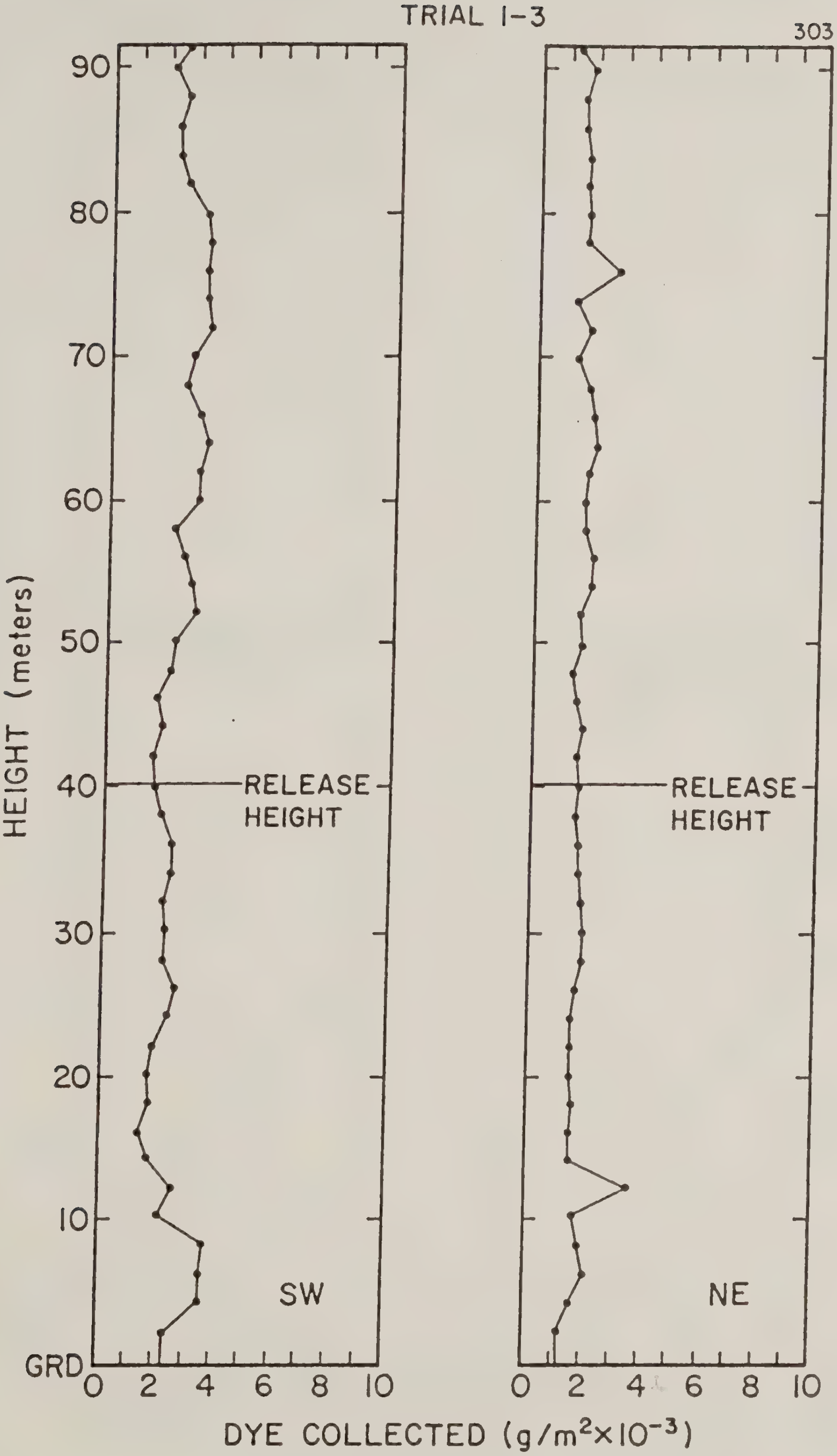

Figure 4-32. Vertical Profile of Dye Collected in Trial 1-3 from Ground Level to 90 Meters

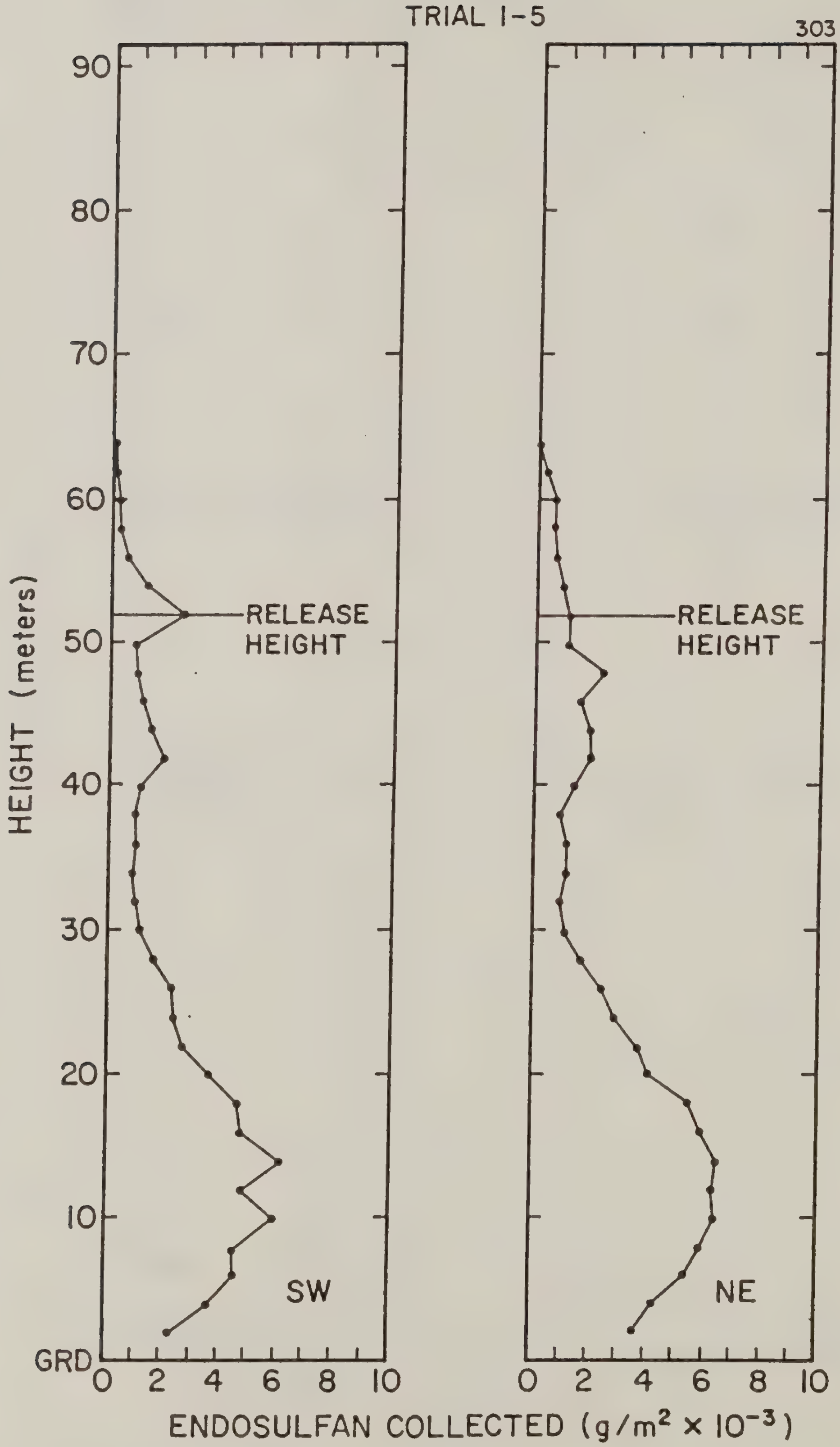

Figure 4-33. Vertical Profile of Endosulfan Collected in Trial 1-5 from Ground Level to 90 Meters

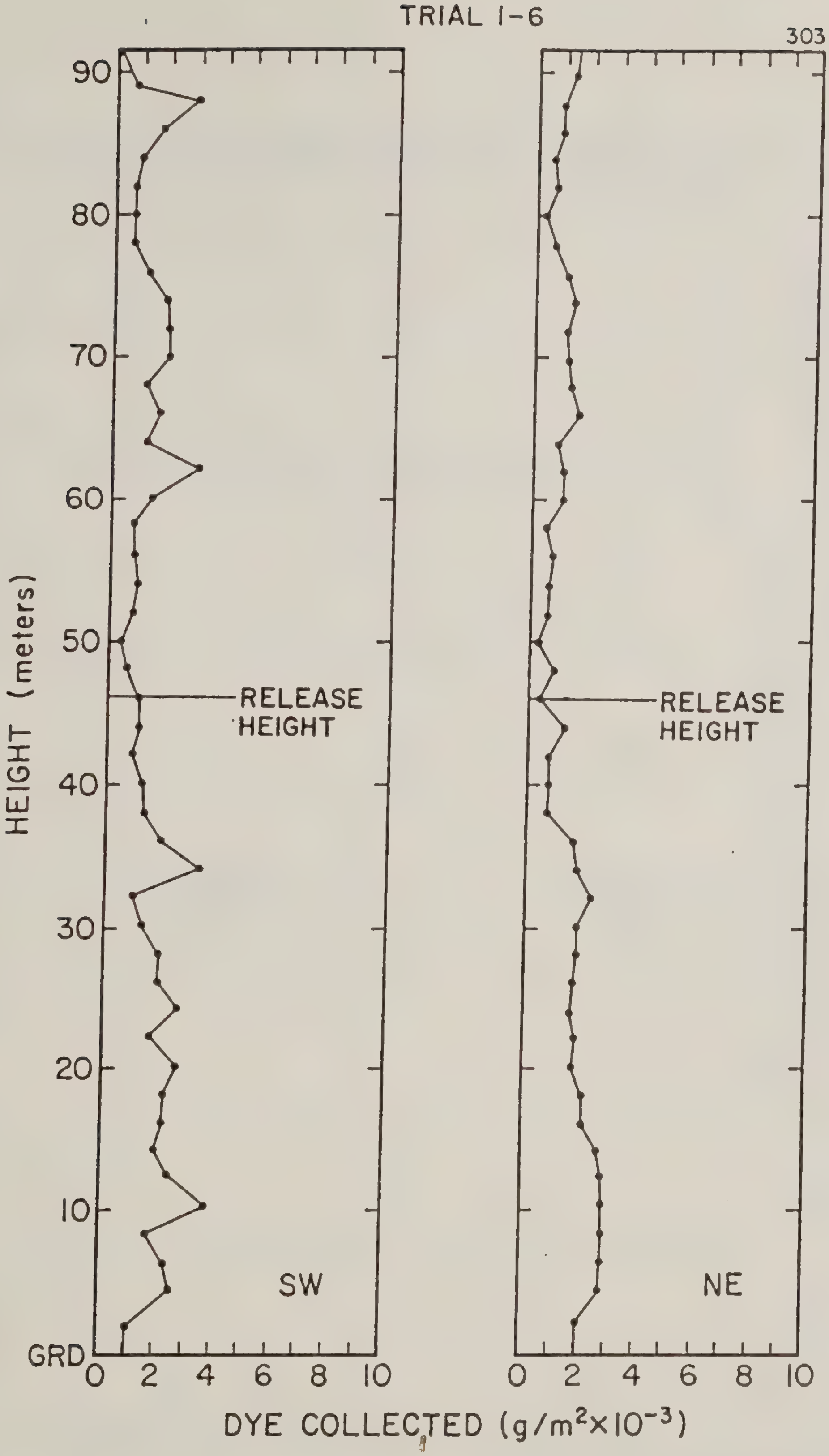

Figure 4-34. Vertical Profile of Dye Collected in Trial 1-6 from Ground Level to 90 Meters

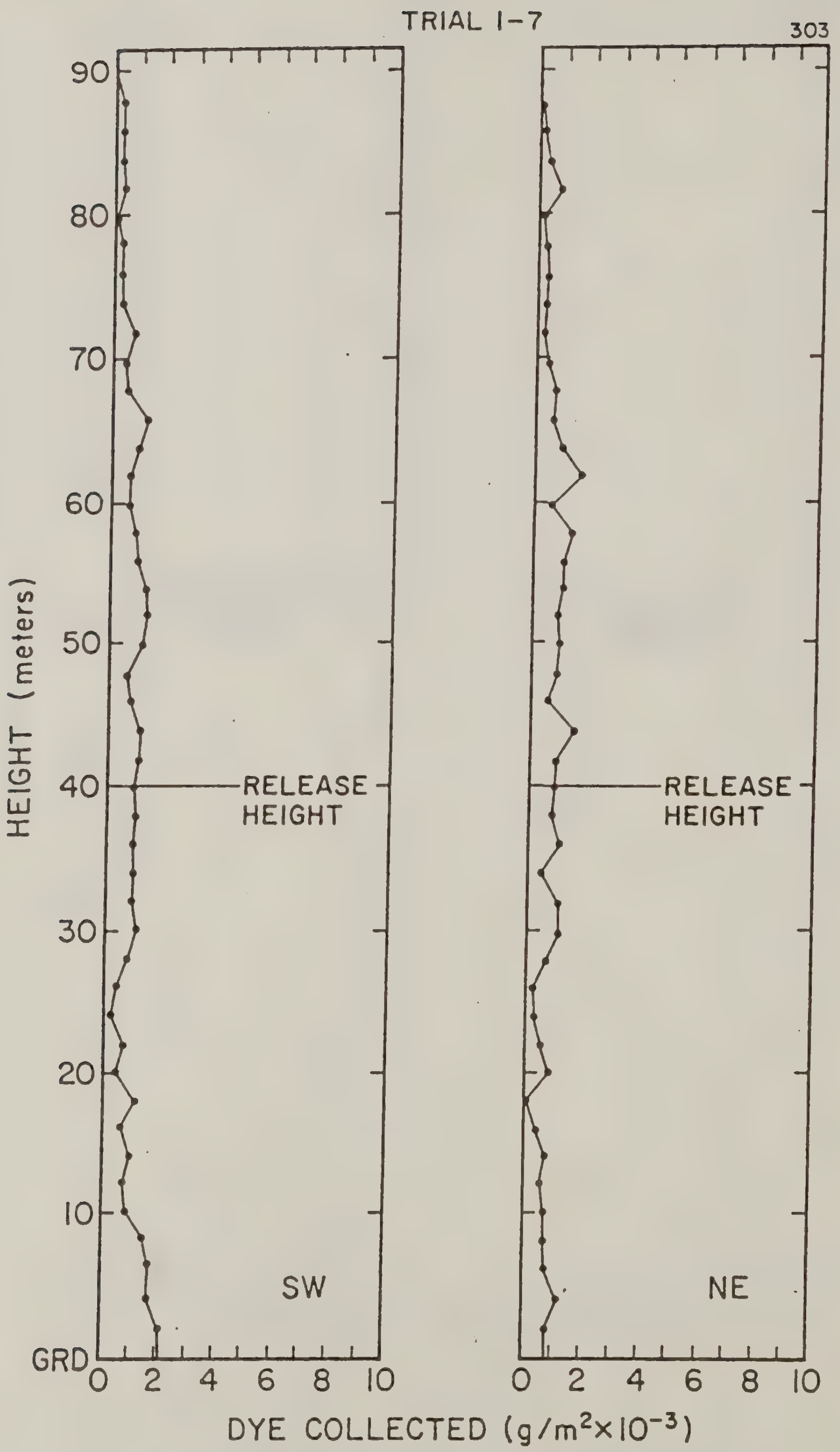

Figure 4-35. Vertical Profile of Dye Collected in Trial 1-7 from Ground Level to 90 Meters

Table 4-4. Vertical Sampling Data and Efficiency for Trial 1-2 (SW)

Sampling Data

Tower Station (m)	Dye Concentration (γ/mℓ)	Dye Concentration (g/m^2)	Area Assigned (m^2)	Amount Dye (g x 10^{-3})	Grid Position	Dye Concentration (γ/mℓ)	Dye Concentration (g/m^2)	Area Assigned (m^2)	Amount Dye (g x 10^{-3})
SW 02	0.29	1.92	3	5.76	SW 50	0.11	0.73	2	1.46
04	0.19	1.26	2	2.52	52	0.10	0.66	2	1.32
06	0.23	1.52	2	3.04	54	0.17	1.12	2	2.24
08	0.21	1.39	2	2.78	56[b]	0.21	1.39	2	2.78
10	0.32	2.11	2	4.11	58	0.25	1.65	2	3.30
12	0.20	1.32	2	2.64	60	0.26	1.72	2	3.44
14	0.23	1.52	2	3.04	62	0.20	1.32	2	2.64
16	0.23	1.52	2	3.04	64	0.23	1.52	2	3.04
18	0.20	1.32	2	2.64	66	0.18	1.19	2	2.38
20	0.22[a]	1.45	2	2.90	68	0.25	1.65	2	3.30
22	0.24	1.59	2	3.18	70	0.16	1.06	2	2.12
24	0.21	1.39	2	2.78	72	0.19	1.26	2	2.52
26	0.27	1.78	2	3.56	74	0.20	1.32	2	2.64
28	0.22	1.45	2	2.90	76	0.14	0.92	2	1.84
30	0.21	1.39	2	2.78	78	0.11	0.73	2	1.46
32	0.15	0.99	2	1.98	80	0.13[a]	0.86	2	1.72
34	0.19	1.26	2	2.52	82	0.15	0.99	2	1.98
36	0.18	1.19	2	2.38	84	0.17[a]	1.12	2	2.24
38	0.23	1.52	2	3.04	86	0.17[a]	1.12	2	2.24
40	0.21	1.39	2	2.78	88	0.19	1.26	2	2.52
42	0.21	1.39	2	2.78	90	0.15	0.99	2	1.98
44	0.16	1.06	2	2.12	92	0.20	1.32	>2	>2.64
46	0.19	1.26	2	2.52					
48	0.19	1.26	2	2.52					
							Total Dye Recovered		122.11

Simulant Dissemination and Meteorology

Flow Rate	14.51 ℓ/sec (230[c] gal/min)	Wind Direction	130° true
Dye Concentration	5.0 g/ℓ	Wind Speed	1.1 m/sec
Aircraft Ground Speed	216 knots (250 mph)	Source Amount	6.49×10^{-1} g/m
Release Height	55 m (180 ft)		
Flight Line	225° True	Efficiency	18.8 percent

(Continued)

[a]Value estimated.

[b]Release Height.

[c]Programmed flow rate; improper valving resulted in a lesser flow rate.

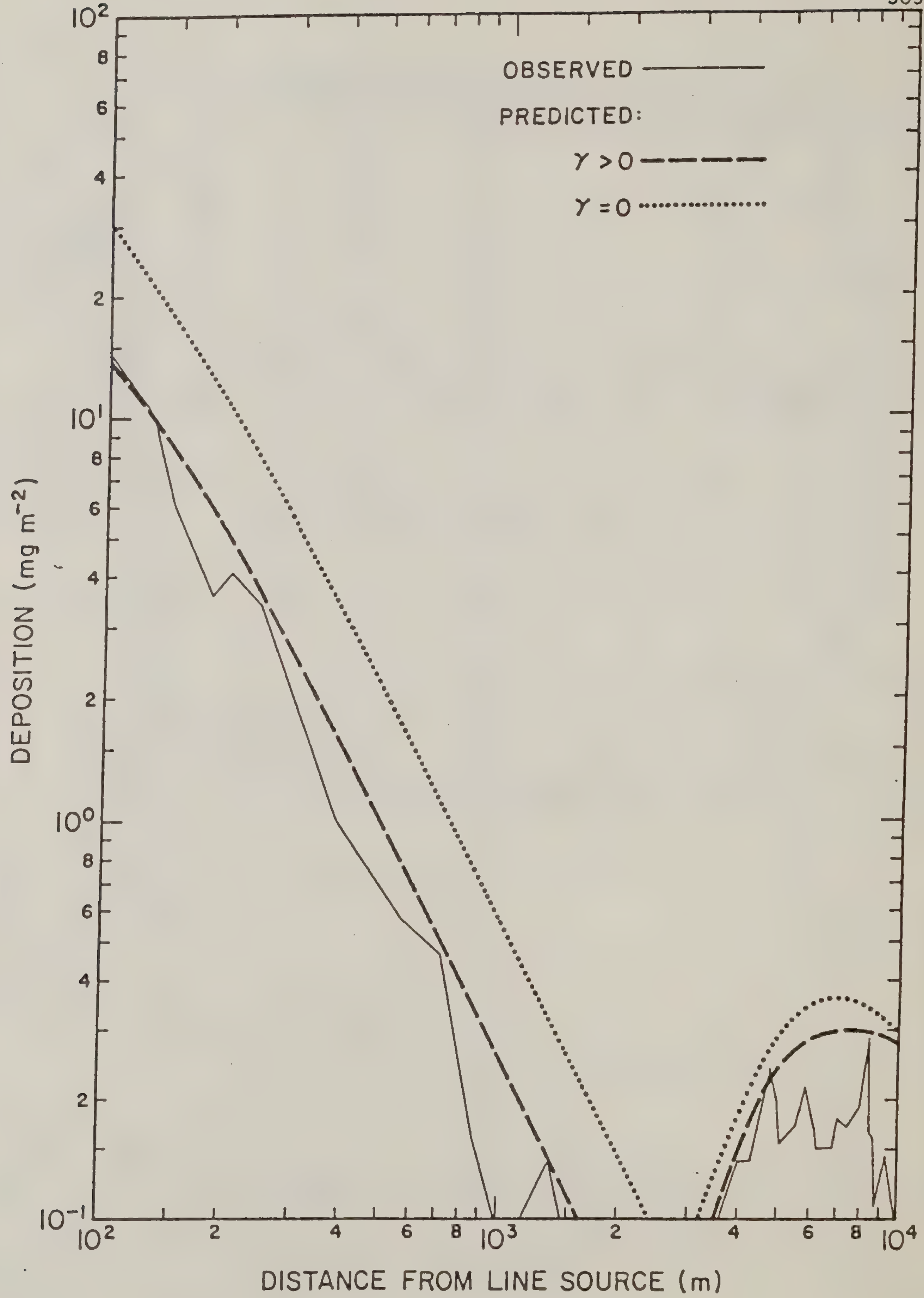

Figure 5-7. Observed and predicted deposition in Trial 1-5.

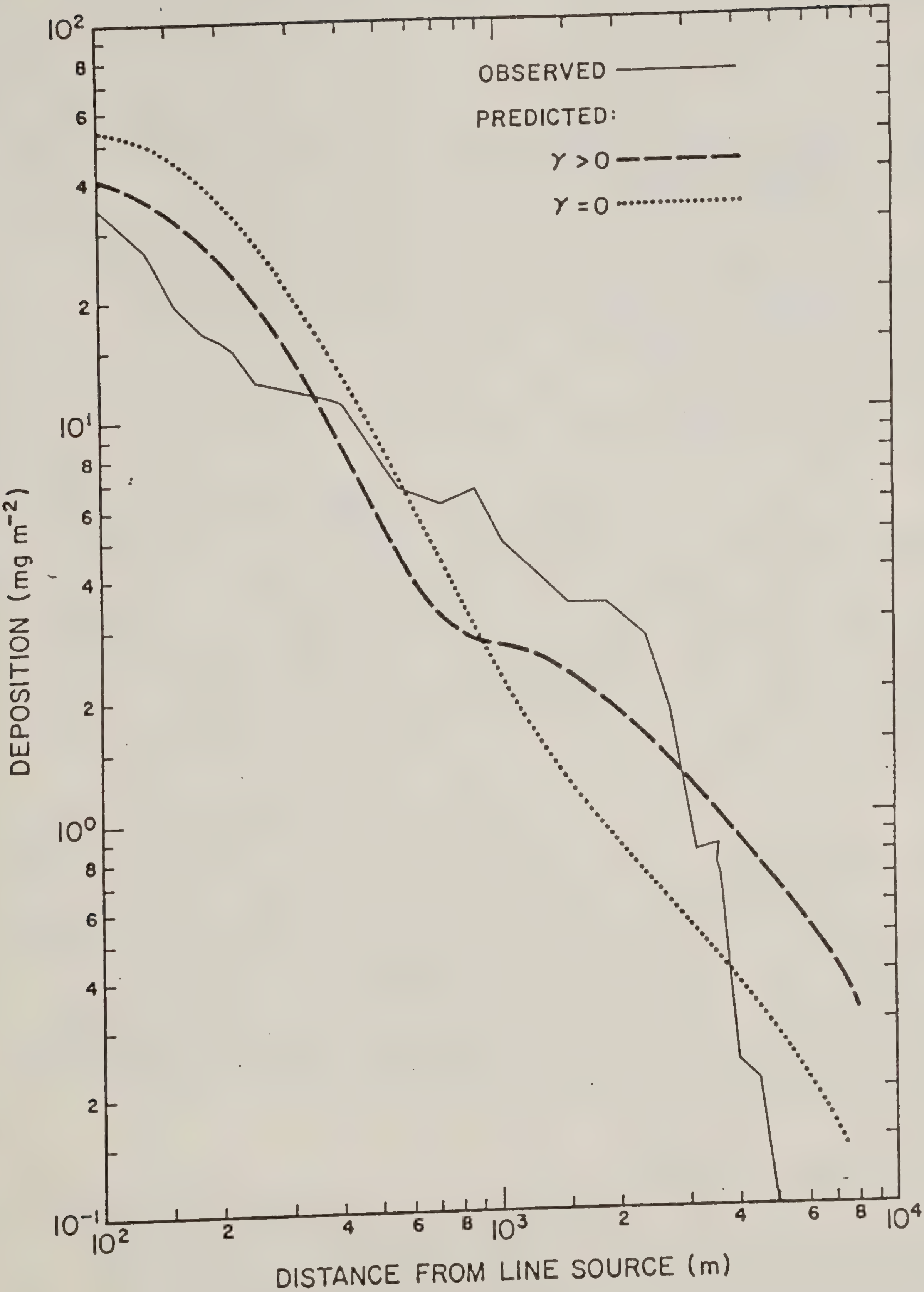

Figure 5-8. Observed and predicted deposition in Trial 1-6.

beyond that distance. According to the test officer's logbook, crews began picking up the deposition samplers, beginning at the flight line and moving downgrid, about 1 hour after dissemination began.

Figure 5-9 shows good agreement between observed and calculated deposition for Trial 1-7. Again, the calculated profile assuming partial reflection of drops at the surface agrees with the observed deposition better than the profile calculated by assuming total deposition or zero reflection. The secondary deposition maximum from reflection at the top of the mixing layer is also apparent. Since the mixing depth is smaller in Trial 1-7 than in Trial 1-5, the secondary maximum in Trial 1-7 occurs closer to the flight line and is larger than the secondary maximum for Trial 1-5.

Profiles of calculated and observed deposition for Trials 2-2R and 2-3, where the flight path was nearly parallel to the wind direction, are shown in Figures 5-10 and 5-11. Because the flight path is approximately parallel to the wind direction, deposition occurs on both sides of the flight path. For this reason, calculated and observed deposition patterns are shown in the figures for both the left and right sides of the flight path. The deposition profiles for Trials 2-2R and 2-3 show that deposition occurred at greater distances to the right than to the left of the flight path. In both trials, the flight path was not directly into the wind, but slightly to the right or clockwise from the mean wind direction.

The calculated deposition profiles agree remarkable well with the observed deposition profiles, especially for Trial 2-3. For Trial 2-2R, Figure 5-10 shows good agreement between calculated and observed deposition to the right of the flight path, but the calculated deposition to the left of the flight path is slightly greater than the observed deposition. Since the flight paths are almost into the mean wind direction, secondary deposition maximums from the reflection of spray drops from the top of the surface mixing layer do not occur within the boundaries of the sampling network. For Trials 2-2R and 2-3, the deposition profiles calculated under the assumption of partial reflection fit the observed profiles better than profiles calculated assuming zero reflection.

5.2.2 Summary of Results

In the use of deposition modeling techniques to characterize the spray deposition observed during the spray trials, attention was centered on the five trials (three crosswind and two inwind) for which complete sets of satisfactory measurements were available. The remaining five trials were excluded from consideration because of uncertainties in the spray-metering system and anomalous deposition patterns caused by large shifts or reversals in wind direction after release.

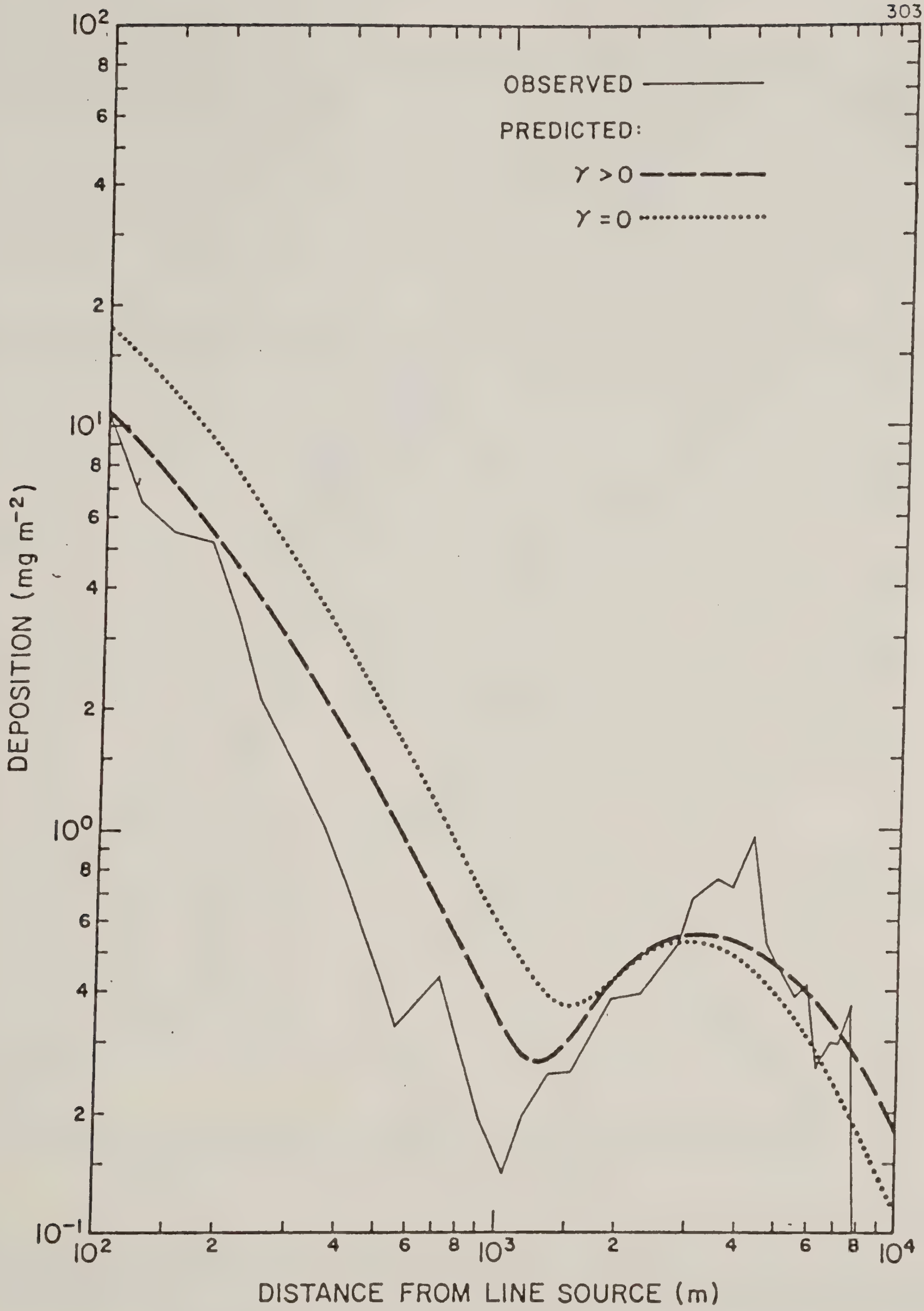

Figure 5-9. Observed and predicted deposition in Trial 1-7.

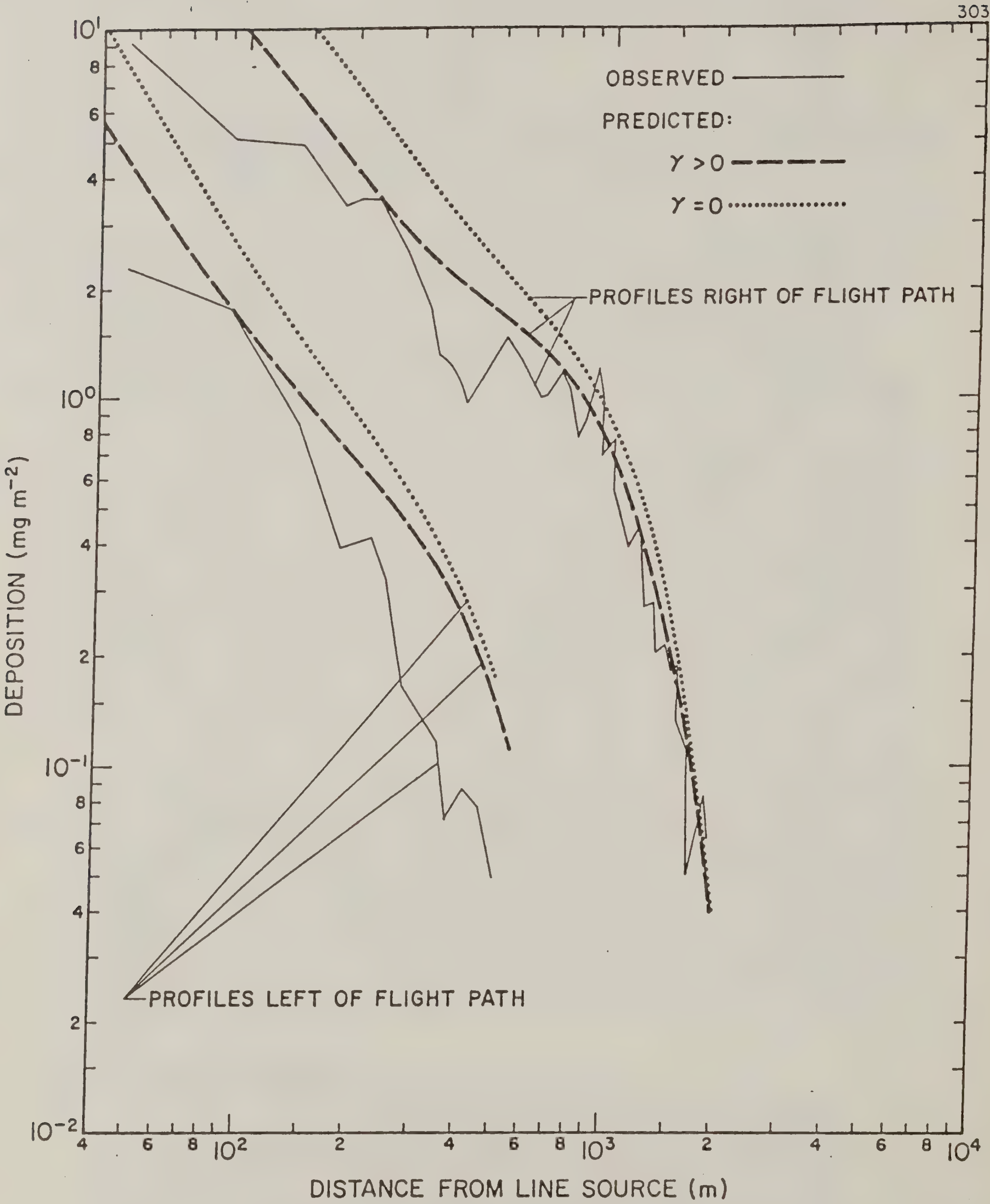

Figure 5-10. Observed and predicted deposition in Trial 2-2R.

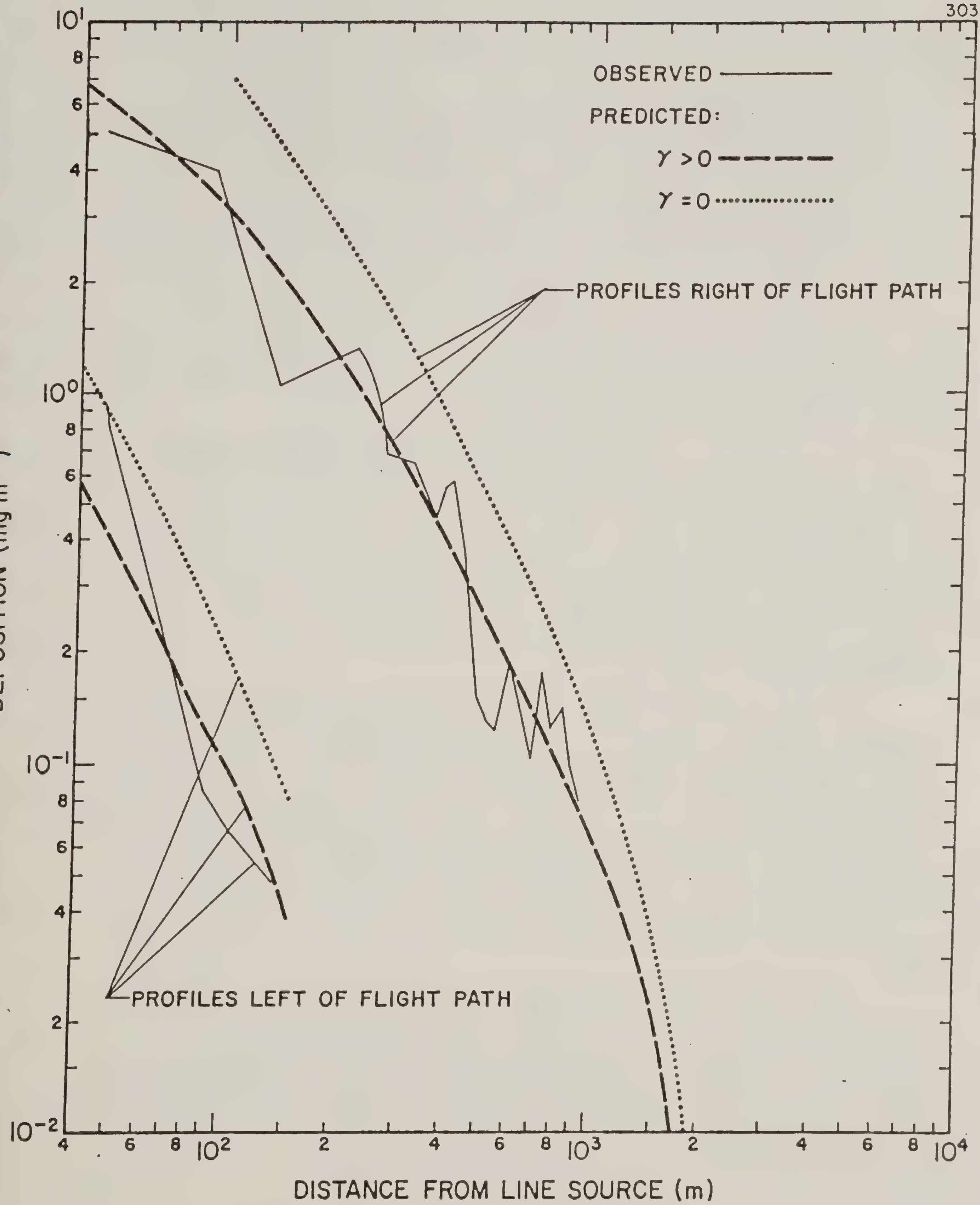

Figure 5-11. Observed and predicted deposition in Trial 2-3.

For these five trials, it has been possible to characterize the deposition pattern produced by the spray system beyond 100 meters from the flight path, by a generalized deposition model for elevated line-source releases using source and meteorological inputs derived from measurements made during the trials. Source inputs for the three crosswind trials were principally obtained from the geometry and composition of the spray cloud a few minutes after the passage of the aircraft as revealed by analyses of spray collections on the 94-meter tower approximately 100 meters downwind from the flight line, aircraft data and drop-size distributions based on the counting and sizing of drop stains on Printflex-card samplers.

No attempt was made in this study to calculate, for any of the five trials, the deposition pattern directly below the flight path. This requires a detailed knowledge of the structure of the trailing vortices and the interactions of this vortex system with the spray droplets and the atmosphere during the first 60 to 100 seconds after the spray is discharged.

One of the new features of the generalized deposition model involved partial-reflection coefficients, which depend on drop size and settling velocity. The partial-reflection coefficients were used to determine, for each drop-size category, the fraction of the spray deposited on the ground. Specific values for the partial-reflection coefficients used in this study may not apply to other sites where the properties of the ground are different. This question can probably be answered only by conducting similar field experiments at other locations.

It is important to note that the success of the generalized deposition model in characterizing the deposition pattern strongly implies that the downwind drift of the spray clouds may also be successfully modeled. Because of time limitations and the fact that no measurements of downwind drift were made, model calculations of downwind drift were not attempted. However, these calculations can be made by using the generalized concentration-dosage model for elevated line-source releases, with a vertical term that includes both settling and partial relfection. This model is available in computerized form and has been successfully used in recent work for DPG.

Only a relatively small number of trials were conducted and some important types of measurements, such as downwind drift, were not included. However, the results clearly demonstrate the feasibility of quantifying the performance of the DC-7B spray system with respect to deposition patterns and downwind drift through the use of modeling techniques in combination with similar field-measurement programs.

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2. Cramer, H.E., *et al.*, 1972: Development of Dosage Models and Concepts. Final Report under Contract No. DAAD09-67-C-0020(R), GCA Tech. Rpt. No. TR-70-15-G, DTC Report No. DTC-TR-72-609, Deseret Test Center, Fort Douglas, Utah.

3. Jones, D.N., 1970: Introduction to Jet-Engine Exhaust and Trailing Vortex Wakes. U.S. Air Force, Air Weather Service (MAC), Technical Report No. 226.

4. McDonald, J.E., 1960: An Aid to the Computation of Terminal Fall Velocities of Spheres. *J. Met.*, **17**, 463.

APPENDIX

IV

Appendix II

AD NO. ______________________
RDTE PROJECT NO. 1-X-6-65704-DL-08
USATECOM PROJECT NO. 5-WE-A00-05A-001
DTC PROJECT NO. DTC-FR-73-317

SERVICES DEVELOPMENTAL TEST

PWU-5/A USAF MODULAR INTERNAL SPRAY SYSTEM

FINAL REPORT

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The USFS in an attempt to define the various meteorological regimes which are encountered in aerial spray operations in mountainous terrain of the western United States contracted the Environmental Science Service Administration (ESSA) to conduct a study on aerosol behavior. The study[17] discusses transport and diffusion modes in five different conditions involving time of day, type of air and type of air drainage. The study also contains a discussion on aerosol mixing, canopy penetration and maximum release height. The ESSA study indicates that aerosol releases from heights greater than 150 feet above the canopy, with disregard to V-shape or U-shape drainage, time of day, and type of air, may preclude aerosol penetration of the canopy, and thus the desired insect mortality. Spraying during one of the unfavorable sets of conditions may very well account for failure of some past spray missions, particularly in the West where extremes exist from hour to hour as compared to relatively stable conditions associated with the topography of the Northeastern United States.

The limited research in this area provides enough information to demonstrate the complexity of the problem but insufficient data to formulate a clear definition.

1.3 DESCRIPTION OF MATERIEL

1.3.1 Spray System

The MISS is an airborne, modular, reusable, high capacity aerial spray system capable of disseminating defoliants, herbicides, pesticides and fertilizers as chemical solutions, suspensions or slurries. The system consists of a power module with a control panel, multiple agent reservoirs, an emergency dump system, wing booms and fuselage spray stations with positive shut-off nozzle valves, a sealed tank venting system and miscellaneous piping and fittings. The system can be assembled in various combinations to fit the ten cargo type aircraft. Figure 1 shows a typical installation of the MISS. Additional tanks may be installed in larger aircraft. For example, in the C-130, eight tanks can be installed, four on each side of the power module. Four tanks, two on each side of the power module, can be placed in the C-54 aircraft. In the C-47/MISS installation, two tanks are installed on the same side of the power module.

The power and control module contains the necessary equipment for control of the filling, priming, recirculating, disseminating,

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[17]ESSA Research Laboratories, Air Resources Laboratory, Silver Spring, MD, Transport and Diffusion of an Aerosolized Insecticide in Mountainous Terrain, Technical Memorandum ERLTM-ARL 6, June 1968.

emergency dumping, flushing and fluid draining operations. The MISS is entirely self-operating, requiring no aircraft power. System power is provided by an air-cooled, internal combustion engine which drives the main pump and air compressor, and generates necessary electrical power. The control panel includes all gauges and controls for complete system operation and monitoring. In addition, the aircraft pilot is provided with controls for agent dissemination and for emergency dumping.

Each agent reservoir has a usable capacity of 500 gallons. Filler cap, vent line, level sensors, inlet and outlet tubes and an emergency dump valve are included as part of the reservoir.

The entire MISS is enclosed to preclude the escape of agent or agent vapors inside the aircraft. The power module and tank modules have retractable casters for mobility.

All nozzle stations are equipped with pneumatically-actuated positive shut-off valves that prevent agent leakage at the nozzles when spraying operations are halted. The valves are "fail-safe" if the pneumatic actuation line fails, i.e., the valves will continue to function, but will seal only against agent pressures less than 5 pounds per square inch, gauge.

Minimal aircraft modification is assured by routing all external plumbing, the tank vent line and the emergency dump outlet line through the aircraft jump doors, and by bonding the external plumbing and wing boom mounting plates to the aircraft with aerospace adhesive.

1.3.2 System Parameters

The parameters listed in Table 1 apply to the complete MISS when installed in specified aircraft.

1.3.3 Zectran

The Zectran (4-dimethylamino-3, 5-xylyl methyl carbamate) formulation consisted of 24 ounces (1.5 pounds) of Zectran in solution with one gallon of tri-propylene-monomethyl glycol ether (TPM). This mixture was designated as Zectran FS-15. One gallon of the Zectran FS-15 solution was mixed with 9 gallons of either Number 2 Fuel Oil or odorless kerosene (i.e., 0.15 pound of Zectran per gallon of fluid). The solution was dyed with Oil Red dye, chemical index (CI) 258 at the rate of 1.0 percent weight per volume. (Oil Red is a standard dye used by DTC.) The mixture was compatible with the Printflex sampling card and the Automatic Spot Counting and Sizing system (ASCAS) employed routinely at DTC. Rhodamine B extra base dye has been used successfully

Table 1. MISS Parameters

Smallest System	2 tanks, 1 power module
Largest System	8 tanks, 1 power module
Capacity	4,000 gallons (maximum)
Dissemination Rate	2.5 gpm (minimum) 600 gpm (maximum)
Flow Rate Monitoring Error	less than $\pm 5.0\%$ (from 2.5 to 600 gpm)
Suction Filling Rate. (Using a 50 foot, 2-inch diameter hose, with water)	145 gpm (57 inch lift) 125 gpm (16.5 foot lift)
Suction Filling Rate. (Using a 50 foot, 2-inch diameter hose with 55 gallon drum suction probe attached, with water)	75 gpm (57 inch lift) 50 gpm (16.5 foot lift)

by the USFS[18] in field tests with Zectran. However, Rhodamine dye fades more rapidly than Oil Red dye in sunlight, and is less favorably to ASCAS assessment.

1.4 TEST OBJECTIVE

To determine the suitability of the U.S. Air Force PWU-5/A Modular Interval Spray System (MISS) for aerial dissemination of insecticide aerosols.

[18]U.S. Department of Agriculture, Pacific Northwest Forest and Range Experimental Station, Corvallis, OR. Progress Report, A Field Experiment in Determining the Effectiveness of Fluorescent Tracer Rhodamine for Assessing Spray Deposit of Registered Zectran Formulation (Nezperce National Forest, Idaho 1971), by B. Maksymiuk, et al. 1971.

1.5 SCOPE[19]

This test consisted of seven trials, six conducted on the Horizontal Grid at Dugway Proving Ground (DPG), Utah, and one in the Lolo National Forest, Montana. The test was conducted in the spring of 1972. Four test phases, designated as A, B, C and D, were established. The test scope and test matrix are summarized in Table 2.

1.5.1 Phase A

Phase A consisted of three Zectran trials, two with Printflex card samplers and one with Printflex cards, coated glass slides and spruce budworm larvae (SBWL). Trials were conducted using the USFS spray system installed on a contractor C-47 aircraft to establish a baseline consistent with the Zectran spray license criteria. These baseline data were compared with the results of subsequent trials with the MISS.

1.5.2 Phase B

Phase B consisted of two preliminary trials with the MISS to check deposition characteristics and associated system operating parameters.

1.5.3 Phase C

Phase C consisted of one trial to characterize the MISS performance and to determine whether the system was compatible with the Zectran spray license criteria.

1.5.4 Phase D

Phase D comprised one extensive mission over an area selected by USFS in which approximately 3,000 acres infested with SBWL were partially sprayed to evaluate the effectiveness of the MISS for Western spruce budworm suppression. The USFS prepared the detailed work plan[20] for the operational application of Zectran, supervised and conducted the field efforts, evaluated the effectiveness of the system, and prepared

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[19]The USAF withdrew its requirement to conduct the test of MISS during the test preparatory period (Message, DTC 0009, CS, USAF, Washington, D.C., 3 June 1972, subject: DTC Support). The deletion did not, however, cancel the work which was already in progress for the U.S. Department of Agriculture. The USAF had committed the MISS to the USFS for evaluation on U.S. National Forest land and it was not feasible to withdraw from the commitment at such a late date.

[20]U.S. Forest Service, Region 1, Missoula, MT. Work Plan Demonstration of the PWU-5/A Modular Internal Spray System for Western Spruce Budworm Control

Table 2. Test Scope and Matrix Summary, DTC Test 72-317

Test Phase	Type Spray System	Trial No.	Location of Trial	Date of Trial	Release Height (ft)	Purpose - Data Required[a]
A	USFS	FS-1 FS-2 FS-3	DPG	27Apr72 27Apr72 27Apr72	150-300	To establish a baseline with USFS system compatible with Zectran spray license criteria. Deposition density, area coverage, droplet spectra, liquid recovery, swath width and effectiveness against spruce budworm larvae.
B	MISS	FS-4 FS-5	DPG	24Jun72 24Jun72	150-300	Preliminary Trials: Deposition characteristics associated with system operating parameters. Visual inspection of deposition and droplet size to specify operating parameters for desired results.
C	MISS	FS-6	DPG	25Jun72	150-300	Comparison with baseline established in Phase A to demonstrate that MISS meets Zectran license criteria. Same as Phase A.
D[b]	MISS	FS-7	Lolo National Forest	29Jun72	145-150	To demonstrate the effectiveness of the MISS to suppress spruce budworm larvae in an infested coniferous forest. To investigate scavenging effect of coniferous forest on aerosolized materials. Deposition characteristics and effectiveness under operational conditions. (Difference in deposition density between top and beneath forest for range of droplet size increments.

[a]Test criteria were as follows: Deposition level = 1 gallon/acre (0.019 g/m^2); droplet mmd = $\simeq$ 113 microns; type sortie - inwind release; flow rate = 150 gallons/minute; aircraft speed = 125 knots.

[b]This phase was conducted after the MISS met the Zectran spray license criteria.

and submitted an environmental impact statement for submission to the Environmental Protection Agency (see Appendix II).

1.6 SUMMARY OF RESULTS AND CONCLUSIONS

1.6.1 Droplet Mass Median Diameter

The estimated mmd of the mixture of Zectran FS-15/Fuel Oil disseminated by both the C-47/USFS spray system and the C-47/MISS was 120 $\pm$ 10 microns.

1.6.2 Deposition Density

The maximum deposition density achieved during the test by both spray systems was $\leq$ 800 milligrams per square meter (mg/m^2) for Zectran FS-15 mixture (16 mg/m^2 for Zectran insecticide). These deposition densities correspond to $\leq$ 1 gallon per acre of Zectran FS-15 mixture (18 mg/m^2 of Zectran insecticide), which is within the restrictions of the Zectran license for suppression of the Western spruce budworm using aerial spray application techniques.

1.6.3 Effective Deposition Density for Open Terrain

A deposition density of Zectran insecticide or Zectran FS-15/Fuel Oil mixture of 2.0 mg/m^2 (insecticide) or 90 mg/m^2 (mixture) will produce 100 percent SBWL mortalities within 24 hours after application, in open terrain.

1.6.4 Effective Swath Width for Open Terrain

The effective swath width was defined as that width of the deposition pattern which will produce 100 percent SBWL mortalities within 24 hours after application of the spray mixture. The effective swath width for both systems (spray released at the rate of 150 gallons per minute, from aircraft flying at an air speed of approximately 130 knots, at a height of 150 to 200 feet above ground level) was 900 feet ($\simeq$ 300 meters) for inwind flights, and 1,200 feet ($\simeq$ 360 meters) for crosswind flights.

1.6.5 Required Distance Between Spray Paths for Open Terrain

The estimated deposition levels achieved on the operational spray mission (Phase D) were 300 to 400 mg/m^2 for the Zectran mixture (corresponding to a Zectran density of 6.0 to 8.0 mg/m^2 in the open area. The deposition level beneath the coniferous canopy was 100 to 300 mg/m^2 for the Zectran mixture (2.0 to 6.0 mg/m^2 for Zectran insecticide). The deposition level of 90 mg/m^2 for Zectran mixture (1.8 mg/m^2 for Zectran) in open terrain produced a SBWL mortality rate of

100 percent within 24 hours after application in the Phase A trials conducted at DPG with chemical and SBWL sampling. Therefore, it was assumed that the operational mission (Phase D) should have produced a SBWL mortality rate of 60 percent.

1.6.7 Flight Techniques for Spraying

In the operational mission in Montana, the average distance between flight paths was 350 feet (a range between 142 and 406 feet). The deposition level achieved in open areas was in excellent agreement with the results obtained in the DPG trials. Since a deposition level of 100 mg/m^2 for the Zectran mixture (2.0 mg/m^2 for Zectran) was measured on the ground beneath the coniferous canopy, it was apparent that the distance between flight paths could be increased to 500 feet without sacrifice of SBWL suppression effectiveness. A flight altitude of 145-150 feet above the ridge line was maintained on each pass. Changes in spray release elevation, to conform with changes in canopy height, was not considered to be a major factor. No loss in spray effectiveness was attributed to differences of this magnitude in the canopy height with respect to the spray release elevation.

1.6.8 Apparent Spray Penetration Characteristics

The measured mmd of the droplet spectrum beneath the canopy on the Montana trial was slightly smaller (141 to 177 microns) than the mmd measured in open areas (184 to 193 microns). This finding indicated that fewer of the larger droplets (size > 109 microns) penetrated the canopy than the smaller droplets (size range of 27 to 109 microns). The apparent lack of canopy penetration by the larger droplets resulted in a significant reduction in the total mass deposited beneath the canopy when compared to mass deposited in open terrain. Droplets in the 130 to 174 micron range comprised 56 percent of the mass measured under the canopy. This finding explains why the mmd under the canopy was 40 microns less than the mmd measured in open terrain.

1.6.9 Mathematical Model[21] Predictions for Spray Operations in Open Terrain

A modified elevated point source mathematical model was used to predict area coverage and swath width for selected deposition levels for the C-47/USFS spray system. Model input parameters (source configuration, droplet size distribution, wind speed, dissemination time, etc.) were computed using data obtained from Trials FS-1 and FS-3. The predictions were compared to the empirical field test results obtained from Trial FS-1. Excellent correlation for swath width ($\pm$ 10 percent of actual test results) was achieved.

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[21]Deseret Test Center, Fort Douglas, UT. Development of Elevated Point Source Model (U), by E.G. Peterson, et al. DTC-TR-71-207, June 1971.

SECTION 2. DETAILS OF TEST

2.1 TASK OBJECTIVES

a. To obtain data on Zectran deposition density and area coverage when dispersed by MISS to estimate total liquid recovery on the ground.

b. To determine the swath width for the deposition level of interest for Zectran dispersed by MISS.

c. To obtain data on the droplet spectrum for the MISS.

d. To determine the effectiveness of the MISS in suppression of SBWL in an infested forest area.

2.2 CRITERIA

2.2.1 Operational Parameters for Application of Zectran

a. Aircraft Speed: 130 knots, indicated air speed.

b. Dissemination Height: 150-300 feet above the surface.

c. Wind Speed: 0-8 knots.

d. Required Deposition Level: 0.018 grams per square meter (1 gallon/acre).

e. Droplet Size Distribution (mmd): $\simeq$ 113 microns (per design criteria).

2.2.2 Meteorological Limitations

There were no meteorological limitations for wind direction, relative humidity, temperature gradient or cloud cover. The limitations for other meteorological parameters were:

a. Wind Speed: 0 to 8 knots (0 to 4.1 meters per second; 0 to 9.2 miles per hour) with 2 to 8 knots desired, measured at the 2 meter level.

b. Air Temperature: 50° to 80° F, measured at the 1 or 2 meter level.

c. Visibility: Adequate to permit target acquisition and photography.

d. Ground Condition: Dry.

e. Precipitation: None.

On the preliminary trials some of the above limitations were waived due to test schedules; however, data requirements were satisfied.

2.3 SUPPLIES AND FACILITIES

2.3.1 C-47 Aircraft/Spray Systems

One C-47 aircraft with a USFS spray system installed, and one C-47 aircraft with a MISS installed were contracted for by the USFS. Pilots and support crews accompanied the aircraft.

2.3.2 Spray Materials

The USFS supplied 165 gallons of Zectran FS-15 mixture. DTC supplied 1,500 gallons of Number 2 Fuel Oil and Oil Red Dye, CI 258. Six cylinders (bottles) of nitrogen were procured by DTC for force-filling of the spray systems. DTC personnel mixed the Zectran in 400 gallon batches, performed the filling of the spray system, and furnished grid operational support. The Zectran was dyed at the rate of 10 grams of Oil Red Dye per liter of Zectran.

2.3.3 Sampling Equipment and Supplies (Maximum)[23]

The USFS supplied 2,000 SBWL. DTC supplied all other sampling equipment.

2.3.3.1 Phases A and C

Item	Quantity
Printflex Card Samplers	625
Coated Glass Slides	141
Petri dishes, each containing 10 spruce budworm larvae (141 for the grid plus controls and replacements)	200

2.3.3.2 Phase B. On the preliminary trials (Phase B), the sampling was restricted to a maximum of 600 Printflex cards.

[23]An operational decision was made by the plans officer to select the grid segment and the amount of equipment required for each test phase.

2.3.3.3 Phase D. The primary sampling required to assess the effectiveness of the MISS against a SBWL infested coniferous forest were specified after site survey was accomplished by the DTC personnel. A total of 250 Printflex card samplers were used (see Appendix III).

2.3.4 Meteorological Equipment

a. For each trial of Phase A, B and C, one 48-meter profile mast, four 2-meter anemometer wind instruments, and necessary equipment to obtain standard surface and test control observations.

b. For the Phase D trial, three 2-meter masts equipped to measure and record wind speed and direction, pilot balloon (PIBAL) equipment and smoke sources.

2.3.5 Photographic Equipment

a. Microfilm camera for photographing Printflex card samplers.

b. Photographic instrumentation for recording aircraft heading, spray release height and altitude.

2.4 METHOD

2.4.1 Pretest Technology

Droplet and deposition sampling techniques were developed prior to the conduct of each trial.

2.4.1.1 Phase A Trials. Three Zectran demonstration trials were conducted using a C-47 aircraft equipped with USFS spray system to establish a baseline for the MISS Zectran trials. These data and those obtained from the MISS trials were compared to assure that the Zectran deposition levels produced by the system were within the specified range required by the Zectran licensee.

2.4.1.2 Phase B-Preliminary Trials with MISS. The MISS was exercised to define the operating parameters (flow rate, system pressure, nozzle size relationship and number of nozzles required) and target acquisition procedures to be used on the test.

Zectran had never been applied with the MISS; therefore, one preliminary trial (Trial FS-4) was conducted to provide a qualitative assessment of the dissemination characteristics of Zectran applied by the system. These data permitted establishment of realistic test design procedures for quantitative assessment of system capabilities (Phase C).

Sampling was restricted to less than 600 Printflex cards per run. The cards were inspected visually to qualitatively estimate the dissemination.

2.4.1.3 Zectran License Requirements. The MISS application of Zectran required approval by USFS. The license specified that Zectran applications must be performed or supervised by the USFS. The Phase A trials were performed at DPG with Zectran dispersed from the C-47/USFS spray system by the USFS with USFS contractor aircraft. The MISS trials were evaluated by the USFS representatives, who certified that the spray techniques proposed did meet the U.S. Department of Agriculture criteria, and that the conditions of the license had been met.

2.4.2 Aircraft Operations

2.4.2.1 Phase A. On each baseline trial, the C-47/USFS spray system (filled with 200-400 gallons) flew 150 to 300 feet above terrain at a speed of 130 knots (150 mph) into the prevailing wind. The material was released at the rate of 150 gallons per minute for 1 minute duration. Release started 0.5 mile upwind of the grid, and terminated approximately 0.75 mile past the downwind perimeter of the grid array.

2.4.2.2 Phases B and C. The aircraft flew a preplanned course. The approximate flow rate and delivery technique were prescribed by the USFS for the release of Zectran on the target grid. The release height, system operating parameters and number of nozzles to be used for each trial of Phase C were defined, utilizing the data obtained in the preliminary trials of Phase B. On each trial, the aircraft flew into the wind at a height specified by the test officer. System loading, evacuation and clean-up were performed by USFS personnel with the assistance of DTC personnel.

2.4.3 Sampling Procedures

The target grid array (Figure 2-1) consisted of a square area (731.2 x 731.2 meters or 2,400 x 2,400 feet) at the Horizontal Grid, DPG. A total of 2,401 sampling positions were surveyed. The grid comprised 49 rows and 40 lines of horizontal sampling positions. The sampling positions, at ground level, were spaced at 50 foot (15.2 meter) intervals. The number of sampling positions utilized in a given trial varied in accordance with the trial objectives.

2.4.3.1 Phase A. On each trial of Phase A, Printflex card samplers were positioned at each of 625 stations shown in Figure 2-1. The spacing between samplers was 100 feet. Coated glass slides were positioned at each of the 141 special sampling stations.

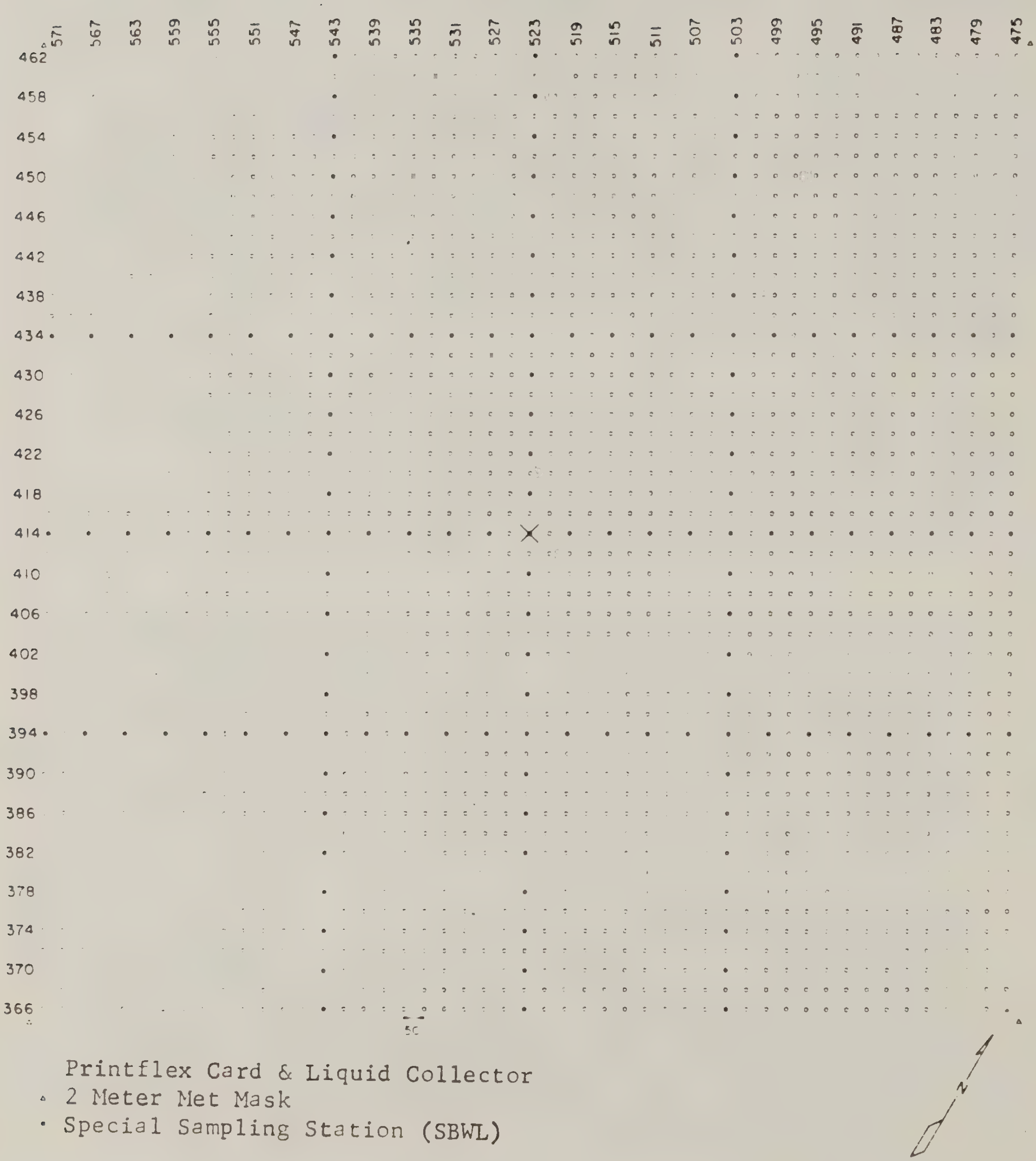


Figure 2-1. Grid Array for DPG Trials

Petri dishes, each containing 10 SBWL, were placed at each of the 141 special sampling positions on the third trial (Trial FS-3). (The SBWL were stored in a temperature and humidity controlled room prior to the trial.) The data from these trials indicated that a sampling density of 100 foot intervals was adequate; subsequent phases were conducted using this density.

Each petri dish containing SBWL was placed on a 4 x 4 inch block of wood to reduce mortalities which could have resulted from surface heating. Controls were handled as specified by USFS. After the trial was conducted, the SBWL were collected, placed in a temperature controlled vehicle and transported to the holding room. USFS personnel performed the mortality count 24 hours after exposure to the Zectran.

2.4.3.2 Phase B. On each Phase B trial, 600 Printflex cards were positioned on a portion of the grid. The test officer selected the segment of the grid to be used based on the prevailing meteorological conditions for each trial.

2.4.3.3 Phase C. On the Phase C trial, the grid setup was identical to that described for Phase A. Results from previous trials indicated that samplers spaced at 100 foot intervals were adequate.

2.4.3.4 Phase D. On Phase D, the sampling procedures were specified by USFS (Appendix II). Locations of sampling lines (approximately 10 rows of 25 Printflex card samplers spaced at approximately 50 foot intervals) were specified after a site survey had been conducted as were the locations for other samplers and the meteorological wind sensors.

2.4.4 Procedure for Meteorological Measurements

2.4.4.1 Phases A, B and C

a. The 48-meter profile mast was located in the vicinity of the target array. The profile mast was instrumented to measure wind speed at 0.5, 1.0, 2.0, 4.0, 8.0, 16.0, 30.0 and 45.7 meters above ground; wind direction at 2, 16, 32 and 48 meters above ground; and temperature gradient between 0.5 meter and 1, 2, 4, 8, 16 and 32 meters above ground level.

b. One 2-meter mast was located at each of the four corners of the grid array to measure and record wind speed and direction at the 2-meter level.

c. Standard surface observations (dry and wet bulb temperatures and cloud cover) were taken 1,500 meters northeast of grid center. PIBAL observations were taken at the same location, as required, for test control.

2.4.4.2 Phase D. Two 2-meter wind sensors were located at selected sites representative of the general forested area. The sensors measured and recorded wind speed and direction, beginning one hour before the spray mission and until one hour after the spray mission.

2.4.5 Photographic Procedures

Following each trial, Printflex card samplers were collected and held for a period (specified by the DTC Chemical Laboratory) at a temperature ≥ 15.6° C to permit droplet stabilization. The Printflex cards were microfilmed to permit sizing and counting by the ASCAS. When the developed negatives were considered satisfactory for ASCAS processing, the cards were destroyed, or retained as specified by the analyst. All negatives were retained for future reference.

2.5 RESULTS

2.5.1 Laboratory Investigation

a. The relationship of droplet diameter to stain size on the Printflex card samplers was determined to be:

$$\text{Drop Diameter } (\mu) = 20 + 0.197 \left[\text{Stain Diameter } (\mu)\right]$$

b. The dye selected for the Zectran mixture was Oil Red Dye (CI 258) and the amount of dye required to obtain suitable droplet definition on the samplers was determined to be 10 grams per liter of the Zectran mixture.

2.5.2 Droplet Spectra

Visual observation and the ASCAS were used to obtain the droplet spectrum of the ground level deposition pattern of the Zectran spray on the Printflex card samplers. All Printflex card samplers from Trials FS-3 FS-3 and FS-6 were microfilmed. This microfilm was scanned by the ASCAS to obtain spot film images from a 1 centimeter square section of each card. The data obtained from the ASCAS processing were then used to obtain the drop size spectrum and affiliated mmd. Selected samplers were processed by ASCAS on the other trials to confirm the visual evaluations. The relevant definitions and numerical methods required to interpret the entries contained in Tables 2-1 and 2-2 are given below:

a. Stain diameter (μ) upper limits were equal to the product of the film image upper limits and their respective photographic reduction factor.

b. Droplet diameters (μ) were based on the following stain function:

$$\text{Drop Diameter } (\mu) = 20 + 0.197\ [\text{Stain Diameter } (\mu)] \qquad \text{(Eq 2-1)}$$

c. The 16 droplet/stain diameter (μ) category or class averages were based on the expression:

$$\left[U^3 - L^3 \div 3\ (U - L)\right]^{\frac{1}{2}} \qquad \text{(Eq 2-2)}$$

where U = upper limit of the droplet size class

L = lower limit of the droplet size class

d. Droplet masses were based on the density of the Zectran mixture which was 0.847 grams per milliliter.

e. The droplet counts were estimated using the following expression:

$$\sum_{j=1}^{n} \sum_{i=1}^{16} \left\{ 10{,}000 \div (PFR)^2 \right\} C_{ij} \quad A_{ij} \qquad \text{(Eq 2-3)}$$

where PRF = photo reduction factor

C = film stain count

A = sampling area, in square meters

i = stain category or class size

j = area category

$(PRF)^2$ = area of viewing surface in square centimeters

The total deposition pattern was approximately 2 miles long. The grid contained only a representative segment of the deposition pattern applied on each trial. The Printflex card samplers were processed to the maximum extent possible on Trials FS-3 and FS-6. The typical deposition pattern was heavy under the flight line and decreased in deposition density as the distance from pattern center increased. The samplers at or near pattern center could not be processed by ASCAS due to droplet overlap; therefore, these samplers were manually sized using optical devices to permit a realistic estimate of the droplet spectrum for the total deposition pattern contained on the sampling array. It was assumed that this segment of the pattern was representative of the total pattern. The ASCAS estimates (150 microns for both trials) lacked definition for the

Table 2-1. Summary of Droplet Data (ASCAS) for Trial FS-3

ASCAS[a] Setting by Size		Diameter Equivalencies (μ)				Average Drop	Accountable		Percent Mass	
Category Number	Film Image Lower Limit (μ)	Lower Limit		Category Average		Mass[e] x 10^{-9} (g)	Drops[f] (x 10^5)	Mass (g)	[g]	Cumulations
		Stain[b]	Drop[c]	Stain[d]	Drop					
1	0	0	20.0	32	26	8.0	889.5	0.7	0.01	100.00
2	11	60.0	31.8	86	37	22.3	1251.5	2.8	0.03	99.99
3	21	114.6	42.6	140	48	47.7	5190.1	24.7	0.30	99.96
4	31	169.1	53.3	194	58	87.7	10036.8	88.0	1.06	99.66
5	41	223.7	64.1	277	75	184.1	17792.3	327.6	3.94	98.60
6	61	332.8	85.6	386	96	392.4	17555.1	688.9	8.28	94.67
7	81	441.9	107.1	495	118	718.5	16756.2	1204.0	14.46	86.39
8	101	551.1	128.6	604	139	1189.0	12193.4	1449.6	17.41	71.93
9	121	660.2	150.1	741	166	2026.0	8560.6	1734.1	20.83	54.51
10	151	823.9	182.3	904	198	3448.0	2961.7	1021.3	12.27	33.68
11	180	987.5	214.5	1068	230	5419.0	1229.6	666.3	8.00	21.41
12	211	1151.2	246.8	1231	263	8026.0	627.3	503.4	6.05	13.41
13	241	1314.9	279.0	1395	295	11360.0	249.7	283.6	3.41	7.36
14	271	1478.6	311.3	1614	338	17120.0	112.4	192.4	2.31	3.96
15	321	1751.4	365.0	1887	392	26650.0	46.8	124.7	1.50	1.65
16	371	2024.2	418.8	2159	445	39180.0	3.1	12.2	0.15	0.15
						Total	95456.1	8324.4	100.00	

mmd: 157 microns

[a]Automatic Spot Counter and Sizer.

[b]Product of film image setting and Photo Reduction Factor (PRF). The PRF for Trial FS-3 = 5.456; for Trial FS-6 = 5.563; for Trial FS-7 = 5.576.

[c]Based on Equation: Drop Diameter = 20.00 + 0.197 Stain Diameter.

[d]Based on Equation: Category Average = $\{(U^3 - L^3) \div 3(U - L)\}^{\frac{1}{2}}$ (U = upper limit; L = lower limit).

[e]Based on Equation: Drop mass(g) = $\pi/6$ (Drop Diameter, cm)^3 (Agent Density). Note: Agent Density = 0.93 g/cc).

[f]Accountable Number of Drops = $\sum_{1}^{M}(10{,}000\ cm^2 \div \{(1cm)(5.545)\}^2)$(area of assignment m^2 of the affiliated grid position).

[g]As percents of total accountable mass.

Table 2-2. Summary of Droplet Data (ASCAS) for Trial FS-6.

ASCAS Setting by Size		Diameter Equivalencies (μ)				Average Drop	Accountable		Percent Mass	
Category Number	Film Image Lower Limit (μ)	Lower Limit		Category Average		Mass (g) $\times 10^{-9}$	Drops ($\times 10^5$)	Mass (g)		Cumulations
		Stain	Drop	Stain	Drop					
1	0	0	20.0	32	26	8.1	3023.0	2.4	0.01	100.00
2	11	61.2	32.1	87	37	22.9	2689.8	6.2	0.02	99.99
3	21	116.8	43.0	143	48	49.3	21578.4	106.4	0.27	99.98
4	31	172.5	54.0	198	59	91.1	45702.5	416.5	1.05	99.71
5	41	228.1	64.9	254	70	151.8	88496.1	1343.0	3.40	98.65
6	51	283.7	75.9	338	87	287.8	139551.2	4015.9	10.17	95.25
7	71	395.0	97.8	449	108	565.3	88949.3	5028.3	12.73	85.09
8	91	506.2	119.7	589	136	1115.0	84875.7	9464.8	23.96	72.36
9	121	673.1	152.6	755	169	2132.0	37089.8	7908.4	20.02	48.39
10	151	840.0	185.5	922	202	3634.0	12944.6	4704.1	11.91	28.37
11	181	1006.9	218.4	1089	234	5715.0	5340.6	3052.1	7.73	16.46
12	211	1173.8	251.2	1255	267	8470.0	1804.2	1528.1	3.87	8.73
13	241	1340.7	284.1	1422	300	11990.0	786.5	943.3	2.39	4.87
14	271	1507.6	317.0	1617	339	17220.0	357.2	615.0	1.56	2.48
15	311	1730.1	360.8	1840	382	24800.0	99.1	245.7	0.62	0.92
16	351	1952.6	404.7	2090	432	35710.0	33.0	117.9	0.30	0.30
						Total	533321.3	39498.1	100.00	

mmd: 150 microns

outer areas of the pattern where a preponderance of the droplets were ≤ 60 microns in size, and in areas of heavy deposition (> 400 mg/m^2) where droplet overlap precluded ASCAS processing. The ASCAS estimates were adjusted to give more realistic estimates. The estimated mmd for both the C-47/USFS spray system and the MISS were 120 microns, ±20. A summary of the ASCAS data are given in Tables 2-1 and 2-2 for Trials FS-3 and FS-6, respectively.

The glass slide samplers, which were to be used as a backup for analysis of the smaller droplets, were not analyzed because the mmd of 120 microns, ± 20, obtained on the Printflex cards, was in the range for counting by the ASCAS technique.

2.5.3 Swath Width

The effective swath width of the deposition pattern was based on the width of that area within the pattern in which a 100 percent SBWL mortality rate was obtained on Trials FS-2, FS-4 and FS-6. The lowest deposition density associated with areas exhibiting a 100 percent SBWL mortality rate was 90 mg/m^2 of the Zectran mixture. The conversion factor used for computing the amount of Zectran in the mixture was 0.02. Therefore, in open terrain, the minimum amount of Zectran that must be applied to obtain 100 percent mortality is 1.8 mg/m^2. This criterion was used to estimate the effective swath width for each trial. The maximum allowable deposition rate was 1 gallon per acre or 800 mg/m^2 of the Zectran mixture, which corresponds to ≤ 17 mg/m^2 of Zectran insecticide. This deposition density was not exceeded on any trial. The effective swath width for the C-47/USFS system was 900 to 1,100 feet for application over open terrain for inwind and crosswind sorties, and 1,200 to 1,400 feet for the C-47/MISS. A summary is presented in Table 2-3. The swath width increased slightly with an increase in the release height-wind speed product. Crosswind sorties also increased the effective swath width when compared to inwind sorties.

2.5.4 Meteorological

The meteorological conditions which prevailed during each trial are summarized in Table 2-4.

2.5.5 SBWL Sampling Data

SBWL were used to demonstrate the effectiveness of Zectran applications by the C-47/USFS spray system and the C-47/MISS, and to correlate the Zectran FS-15 mixture (or Zectran) deposition density to 100 percent SBWL mortalities. A summary of the SBWL sampling results for the total sampling grid is presented in Table 2-5. Sampling results obtained for each grid position on each trial are contained in Appendix I. Approximately 40 percent of the grid received spray deposition on a given trial. Table 2-5 lists the percent of the grid covered with the deposi-

tion pattern. Within the effective swath, 100 percent SBWL mortality was achieved within 24 hours after spray application.

2.5.6 Target Coverage

Deposition levels were selected based on the following correlating parameters:

Deposition Density (mg/m^2)		Zectran FS-15 Mixture (gal/acre)	24 Hour SBWL Mortality Rate (%)
Zectran	Zectran FS-15 Mixture		
< 1.8	≤ 90	≤ 0.1	0 - 90
1.8 - 3.5	90 - 179	0.1 - 0.22	100
3.6 - 5.9	180 - 299	0.22 - 0.39	100
6.0 - 16.0	300 - 800	0.4 - 1.0	100
≥ 16.0	≥ 800	[a]1.0	-

[a]Maximum allowable deposition per license stipulations.

Contour diagrams for selected trials are shown in Figures 2-2 through 2-6 to illustrate the relative areas covered at selected deposition levels within the swath. The level used to establish effective swath width for open terrain was 90 mg/m^2 for the Zectran mixture (1.8 mg/m^2 for Zectran) which produced a 100 percent SBWL mortality rate within 24 hours after application.

2.5.7 Operational Information

Operational parameters and selected target effects are contained in Table 2-6 for the six trials conducted in open terrain at DPG. The sampling results (deposition density of the Zectran mixture, predominant droplet size, and deposition density for Zectran insecticide) for each relevant sampling position are contained in Appendix I.

Table 2-3. Summary of Effective Swath Width Estimates for Zectran Application Over Open Terrain

Trial Number	Type System	Flight Direction	Release Height (ft)	Effective Swath Width[a] (ft)	Wind Speed at 48-m Level (m/sec)
FS-1	C-47/USFS System	Inwind	174	900	1.5
FS-2		Inwind	203	900	2.2
FS-3		Crosswind	328	> 1,200	2.0
FS-4	C-47/MISS	Inwind	150	1,100	
FS-5		Inwind	150	1,000	
FS-6		Crosswind	140	1,400	3.5

[a]Based on a deposition density of 90 mg/m² for the Zectran mixture or 1.8 mg/m² of Zectran insecticide.

Table 2-4. Summary of Meteorological Data for DTC/USFS Cooperative Spray Program

Datum Description	Trial Number					
	FS-1	FS-2	FS-3	FS-4	FS-5	FS-6
Date (1972)	27 April	27 April	27 April	24 June	24 June	25 June
Time (MST)	0717.18	0915:35	1822:11	0906	1043	0608
Relative Humidity (%)	28	28	29	ND	ND	83
1-m Air Temperature (°F)	44.1	51.9	43.0	ND	ND	52.0
Temperature Gradient (0.5 to 32 m) (C°)	-2.5	-2.1	0.0	ND	ND	ND
2-m Wind Speed (m/sec)	1.5	2.0	2.2	(1.0)[a]	2.0	(3.5)
2-m Wind Direction (deg)	240	345	060	(060)	(350)	(015)

[a]Estimated values are inclosed in parentheses.

Table 2-5. Summary of Spruce Budworm Larvae (SBWL) Sampling Results

Trial	SBWL Mortality Data[a] For Indicated Observation Times								
	6 hours			24 hours			48 hours		
	L	D	% M	L	D	% M	L	D	% M
FS-2[b]	629	553	47.0	581	595	51	567	609	52
FS-4[b]	564	451	44.4	538	477	46.9	-	-	-
FS-6[c]	-	-	-	779	533	40.3	-	-	-

[a] L = number of live SBWL; D = number of dead SBWL; % M = percent mortalities.

[b] The C-47/USFS spray system was used on this trial.

[c] The C-47/MISS was used on this trial.

NOTE: These data indicate that between 40 and 50 percent of the total grid was covered by the Zectran deposition pattern (i.e. ≥ 200,000 of the 585,000 square meters were covered on each trial at the effective Zectran deposition level).

Table 2-6. Summary of Operational Data for DPG Trials

Datum Description	Trial Number					
	FS-1	FS-2	FS-3	FS-4	FS-5	FS-6
Type Spray System	USFS[a]	USFS	USFS	HC[b]	HC	HC
Air Speed (knots, IAS)	127	128	129	115	117	117
Release Height (ft)	174	203	328	150	150	140
Flow Rate (gal/min)	150	150	150	150	150	150
Boom Pressure (psi)	NA[c]	NA	NA	133	133	133
Spray Time (sec)	43	45	66	80	112	76
Amount Released (gal)	107.5	112.5	165	200	280	190
Estimated Swath Width (ft)	900	900	> 1,200	1,100	1,000	1,400
Estimated mmd (μ)				120 ± 10		
SBWL Mortalities (%)[d]	NA		NA			
Observation Time = 6 hr		47		44.4		ND[e]
Observation Time = 24 hr		51		46.9		40
Observation Time = 48 hr		52		ND		ND

[a] C-47/USFS spray system
[b] C-47/MISS
[c] NA denotes not applicable
[d] Percent SBWL mortalities for total grid. 100 percent SBWL mortality was achieved in the estimated swath width (effective swath width) within 24 hours after Zectran application.
[e] ND denotes no data

2.6 RESULTS OF OPERATIONAL DEMONSTRATION AT LOLO NATIONAL FOREST, MONTANA

2.6.1 Scope of Demonstration

The U.S. Forest Service selected an area comprising 3,000 acres of SBWL infested trees in the Ninemile Ranger District, Lolo National Forest, located approximately 35 miles northwest of Missoula, Montana, as the site for the operational demonstration of the C-47/MISS. The area for Zectran application was located northeast of Ninemile Creek Road extending 1 mile on each side of the Foothill Road from Little Blue Creek to Soldiers' Creek. Four lines of samplers were set out in the test area. Two lines were positioned at ground level under the trees (Rows A and B). One line was positioned in open terrain (Row C), and one line partially in the open and partially under trees (Row D). The demonstration was terminated after four 65-second spray sorties (swaths) due to malfunction of the MISS pump bearings. SBWL mortality was not investigated due to the limited number of swaths. The chemical sampling results were incomplete but warranted evaluation. The results are reported herein.

2.6.2 Operational Effectiveness

A total of four complete passes were made plus a partial pass. Each pass was 2 miles in length ($\simeq$ 65 seconds) and the average release height above the ridge line was 145 to 150 feet. The estimated area covered with a Zectran FS-15/Fuel Oil mixture at a deposition level of 300 to 400 mg/m^2 (6 to 8 mg/m^2 of Zectran insecticide) was 1 square mile (640 acres or 25.9 hectares). The estimated release height above the road and the forested ridge along with the distance between swaths for each pass are given in Table 2-7 (based on survey data). The average deposition level is based on the distance between passes and the deposition levels achieved for comparable swath widths on the DPG trials. A comparison of the samplers located in the open areas and samplers on the floor of the forest indicated the deposition level on the forest floor was 25 to 75 percent less than the deposition level in the open. Hence, a minimum Zectran deposition level of 2.0 mg/m^2 (100 mg/m^2 of the Zectran mixture) was applied at ground level over the 1 square mile area sprayed. Although no SBWL sampling data were collected in the operation, it was estimated that at least 60 to 75 percent of the area sprayed should have received Zectran deposition levels compatible with the effective SBWL suppression criterion. (i.e. $\geq$ 90 mg/m^2 for the mixture, or 1.8 mg/m^2 for Zectran insecticide).

The aircraft passes were executed during a period of light winds ($\simeq$ 1 to 2 meters per second) and the wind direction was perpendicular (crosswind) to the line of flight.

Table 2-7. Summary of Operational Data for Trial FS-7 in Lolo National Forest, Montana

Pass Number[a]	Spray Release Height (ft)		Distance Between Passes (ft)
	Above Road[b]	Above Ridge	
1	395	145	---[c]
2	384	144	330
3	373	148	224
4	395	145	142
[d] 5	370	150	406

[a] The time of spray duration was approximately 65 seconds for each pass, except Number 5.
[b] The road gradually increases in elevation from 0 to 86 feet measured from the boundary of the test site to the area of Pass Number 5.
[c] Pass Number 1 was located 156 feet upwind of the edge of the test site boundary.
[d] The mission was terminated before Pass Number 5 was completed.

2.6.3 Chemical Sampling

The chemical sampling results obtained on Trial FS-7 were minimal (Table 2-8). Rows A and B were not considered as in the open, and sampling data from these rows were not considered for beneath canopy data comparisons.

a. Row A was located beneath the trees near the spray release initial point. The spray pattern was displaced beyond the Row A location prior to deposition; therefore, the Zectran loading was not representative of the operation.

Table 2-8. Deposition and Droplet Data for FS-7 Trial

Position Number	Row A		Row B		Row C[a]		Row D	
	mg/m^2	micron	mg/m^2	micron	mg/m^2	micron	mg/m^2	micron
29							1	100
30							2	100
31							2	100
32							3	120
33							3	120
34							150	200
35							160	200
36							240	200
37			2	120			200	200
38			4	120			180	200
39	2	240	1	100	2	400	150	160
[a]40	5	240	0	0	2	340	200	170
	10	240						
41	5	240	8	160	2	250	260	200
42			5	160	70	260	260	200
43			200	260	, 100	300	150	190
44			80	200	300	200	110	160
45			80	230	300	180	260	200
46			140	200	400	160	100	200
47			160	200	400	160	200	220
48			210	200	400	150	300	180
49			80	160	300	140	300	200
50			240	180	400	150	400	180
51			300	180	400	150	110	240
52			200	180	400	160	160	220

[a]Position 40 Row A and all positions in Row C were in the open.

NOTE: Evidence of one spruce budworm on cards B-45 and D-43; five on D-44; and at least seven on D-46.

b. The positions receiving deposition on Row B were located under brush and in partially open terrain and, therefore, were not correlated with positions on Row C (which was in the open). The difference in the impaction and/or scrubbing characteristics of a combination of broadleaf and other type vegetation versus coniferous trees was not typical of the primary test site.

The deposition measurements obtained on selected positions of Rows C and D were used to examine the difference in estimated deposition levels and droplet mmd. These selections were based on the position of the samplers with respect to the locations of the swaths and direction of cloud travel. The comparison is given in Table 2-9.

Table 2-9. Comparison of Sampler in Open Terrain and Samplers Under the Coniferous Canopy for Trial FS-7

Row C (Open Terrain)			Row D (Under Trees)			Percent Reduction in DD
Position	DD[a] (mg/m^2)	mmd (μ)	Position	DD (mg/m^2)	mmd (μ)	
C-45	300	180	D-43	150	190	50.0
C-46	400	160	D-44	110	160	72.5
C-46	400	160	D-45	260	200	35.0
C-47	400	160	D-46	100	200	75.0
C-47	400	160	D-47	200	220	50.0
C-47	400	160	D-48	300	180	25.0
C-47	400	160	D-49	300	200	25.0

[a] DD denotes deposition density of Zectran mixture.

These data indicate that 25 to 75 percent of the Zectran mixture was impacted on the needles of the trees. Assuming that the deposition loading for samplers in the open was equivalent to the deposition level at the top of the trees, the average reduction in Zectran mixture due to deposition within the forest canopy was 47.5 percent. Since the deposition level for the open terrain was 300 to 400 mg/m^2 (6.0 to 8.0 mg/m^2 of Zectran insecticide) and the deposition level beneath the trees was 100 to 300 mg/m^2 (2.0 to 6.0 mg/m^2 of Zectran insecticide) and the 100 mortality rate for SBWL within 24 hours for open terrain is 90 mg/m^2 (1.8 mg/m^2 of Zectran), it was estimated that the area sprayed should have resulted in

a SBWL kill of 60 to 75 percent. This estimate is considered to be conservative, since the impaction characteristics for the coniferous trees indigenous to the test site is not known, and a normal distribution of the spray droplets from treetop level to terrain level cannot be assumed with any confidence.

A map diagram of the area of operations is shown in Figure 2-7.

2.6.4 Canopy Penetration Characteristics of the Spray

A review of the data in Tables 2-8 and 2-9 indicates that the spray mass measured beneath the canopy averaged 47.5 percent less than the mass measured in open areas between tree-covered terrain. A comparison of the droplet distribution associated with typical samplers in the open and beneath the canopy is shown in Table 2-10 and Figure 2-8.

Table 2-10. Comparison of Droplet Size-Mass Distribution in Open Terrain and Beneath the Canopy for Trial FS-7

Drop Class Category	Average Droplet Size (μ)	Open Terrain: Average Mass (gm x 10^{-3})	Open Terrain: Percent of Mass	Beneath Canopy: Average Mass (gm x 10^{-3})	Beneath Canopy: Percent of Mass	Ratio Open/Beneath
1	26.3	0.007	0.00	0.007	0.01	0.00
2	43.3	0.035	0.01	0.027	0.03	0.33
3	64.9	0.808	0.25	0.162	0.16	1.56
4	86.7	7.528	2.31	1.160	1.12	2.06
5	108.6	19.133	5.86	5.135	4.96	1.18
6	130.6	31.733	9.73	14.146	13.65	0.71
7	152.5	47.529	14.57	21.890	21.13	0.69
8	174.5	49.128	15.06	21.704	20.95	0.72
9	196.4	39.377	12.07	11.305	10.91	1.11
10	218.4	24.326	7.46	6.167	5.95	1.25
11	240.3	17.217	5.28	4.249	4.10	1.28
12	262.3	14.636	4.49	2.581	2.49	1.80
13	284.3	14.233	4.36	3.287	3.17	1.38
14	311.8	23.108	7.08	6.199	5.98	1.19
15	344.7	19.518	5.98	3.341	3.22	1.85
16	377.7	17.956	5.50	2.23	2.16	2.59

NOTE: Open terrain positions used were C-45, C-46, and C-47. Positions D-43 through D-49 were used for under the canopy entries. All data are based on ASCAS analysis for each sampler.

Figure 2-7. Sampling Array, Phase D

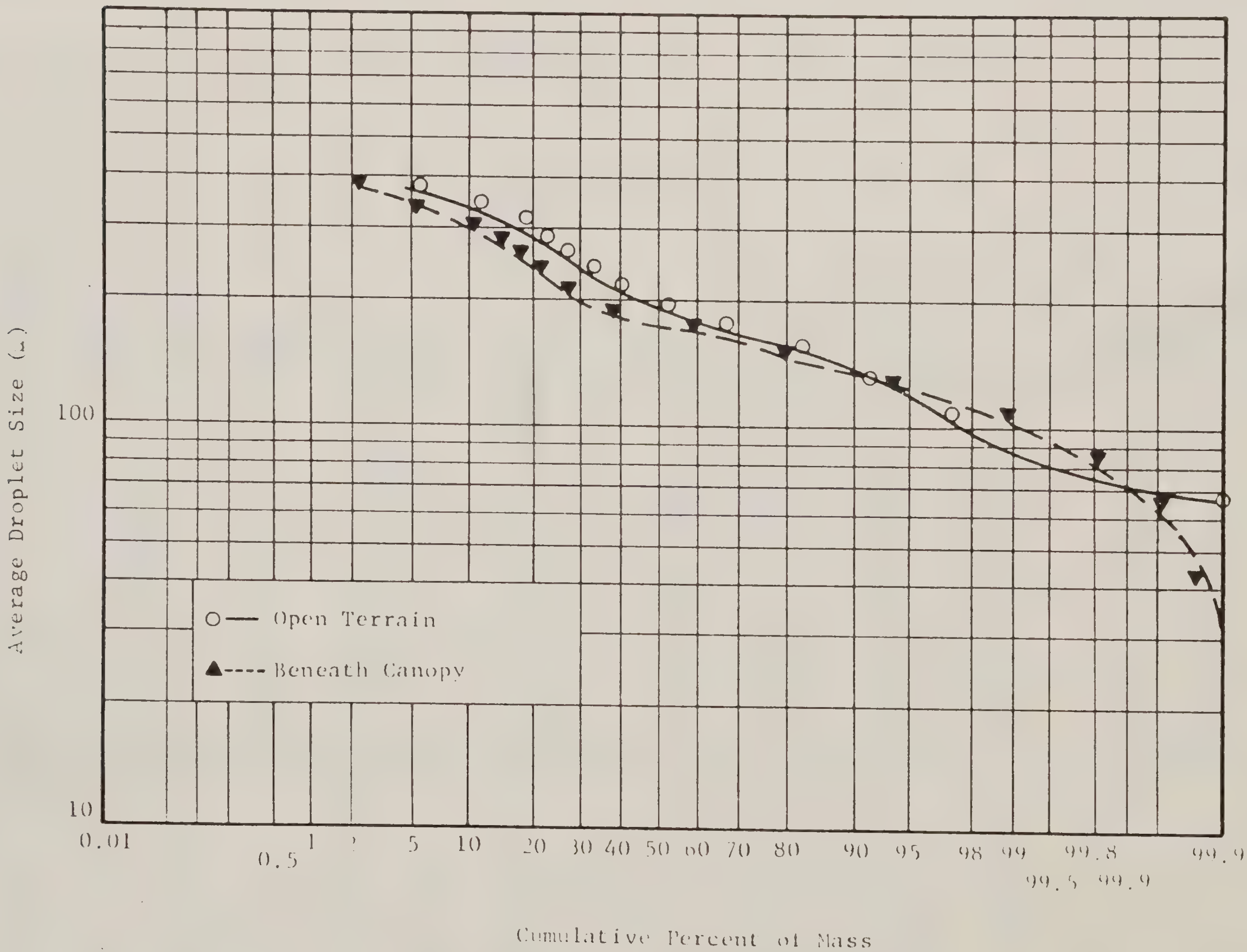


Figure 2-8. Comparison of Droplet Size - Cumulative Mass Distribution for Open Terrain and Beneath the Canopy for Trial FS-7

Table 2-11. Summary of Droplet Data (ASCAS) for Trial FS-7

ASCAS Setting by Size		Diameter Equivalencies (μ)				Average Drop	Accountable		Percent Mass	
Category Number	Film Image Lower Limit (μ)	Lower Limit		Category Average		Mass (g) $\times 10^{-9}$	Drops ($\times 10^{6}$)	Mass (g)		Cumulations
		Stain	Drop	Stain	Drop					
1	0	0	20.0	32	26	8.1	134.5	0.1	0.00	100.00
2	11	61.3	32.1	118	43	36.0	352.6	1.3	0.03	100.00
3	31	172.9	54.1	228	65	121.2	3128.5	37.9	0.85	99.97
4	51	284.4	76.0	339	87	289.3	7027.8	203.3	4.58	99.11
5	71	395.9	98.0	450	109	568.5	6457.1	367.1	8.27	94.53
6	91	507.4	120.0	561	131	987.0	5949.2	587.2	13.23	86.26
7	111	618.9	141.9	673	153	1573.0	4655.3	732.3	16.50	73.03
8	131	730.5	163.9	784	175	2355.0	2856.6	672.6	15.16	56.53
9	151	842.0	185.9	896	196	3360.0	1541.8	518.1	11.67	41.38
10	171	953.5	207.8	1007	218	4618.0	690.2	318.7	7.18	29.70
11	191	1065.0	229.8	1118	240	6156.0	427.3	263.0	5.93	22.52
12	211	1176.5	251.8	1230	262	8002.0	218.1	174.6	3.93	16.59
13	231	1288.1	273.7	1341	284	10190.0	143.4	146.1	3.29	12.66
14	251	1399.6	295.7	1481	312	13440.0	131.5	176.7	3.98	9.37
15	281	1566.9	328.7	1648	345	18170.0	68.7	124.9	2.81	5.39
16	311	1734.1	361.6	1816	378	2389.0	47.8	114.2	2.57	2.57
						Total	33820.4	4438.1	100.00	

mmd: 173 microns

For the comparison in Table 2-10, the sampling positions were selected based on those samplers receiving deposition in the open terrain (Row C) and beneath the canopy (Row D) on Pass Number 3.

The average mass associated with each drop size category for samplers in the open and beneath the canopy were computed by:

a. Multiplying the average number of droplet counts for the sample size used by the average mass for each drop size.

b. The above value was divided by the collection surface area of the Printflex card sampler (i.e. the scan area which was 0.0031 square meters).

c. The percent mass for each drop size category was computed.

d. A ratio for the percent mass associated with each comparable drop size category in open terrain/beneath canopy was computed.

e. These ratios were used as a criterion for determining the penetration efficiency for each drop size category.

The comparison revealed that the mmd for droplets under the canopy ranged from 141 to 171 microns. Droplet samples in the open had mmd ranging from 184 to 193 microns. The droplet distribution appeared to be normal for droplets ≥ 130.6 microns but was skewed to the left of the curve peak for average droplet sizes between 26.3 and 108.6 microns for deposition in the open and beneath the canopy. For droplet sizes of 196.4 to 377.7 microns, which contributed the most to total mass, the ratio of percent mass for open versus beneath canopy deposition was ≥ 1.0 in each case. This finding reflects the fact that the larger droplets did not penetrate the canopy in a manner comparable to the smaller droplets. This lack of canopy penetration by the larger droplets resulted in a significant reduction in mass deposited beneath the canopy. The increase in mass deposited beneath the canopy for average droplet sizes between 64.9 and 108.6 microns was also considered, but only 5 to 8 percent of the total mass was associated with this size range versus 36-50 percent of the total mass associated with the larger droplet range.

A summary of the ASCAS data for the Montana trial (Trial FS-7) is given in Table 2-11.

APPENDIX

V

TRIAL RECORD DPGTR 333
CHEMICAL DISSEMINATION TESTS
OF THE SIMULATED SD-5 DRONE
(MANNED AIRCRAFT), DPGTP 599

Chemical Branch
Test Design and Analysis Division
Technical Plans and Evaluation Directorate
June 1963

U.S. Army
Test and Evaluation Command
Dugway Proving Ground
Dugway, Utah

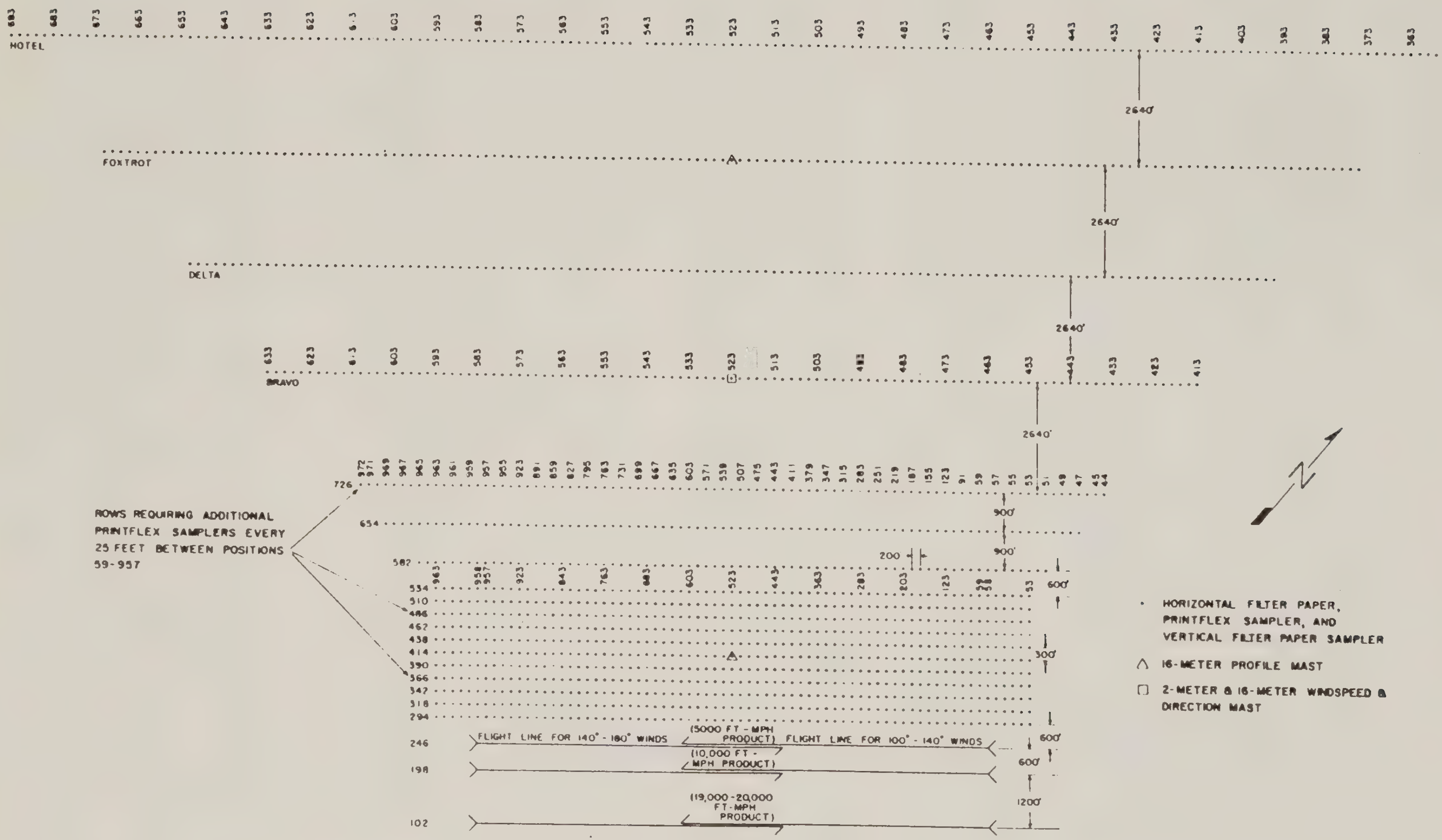


Figure 2 Grid diagram for C 599, Phases A and B

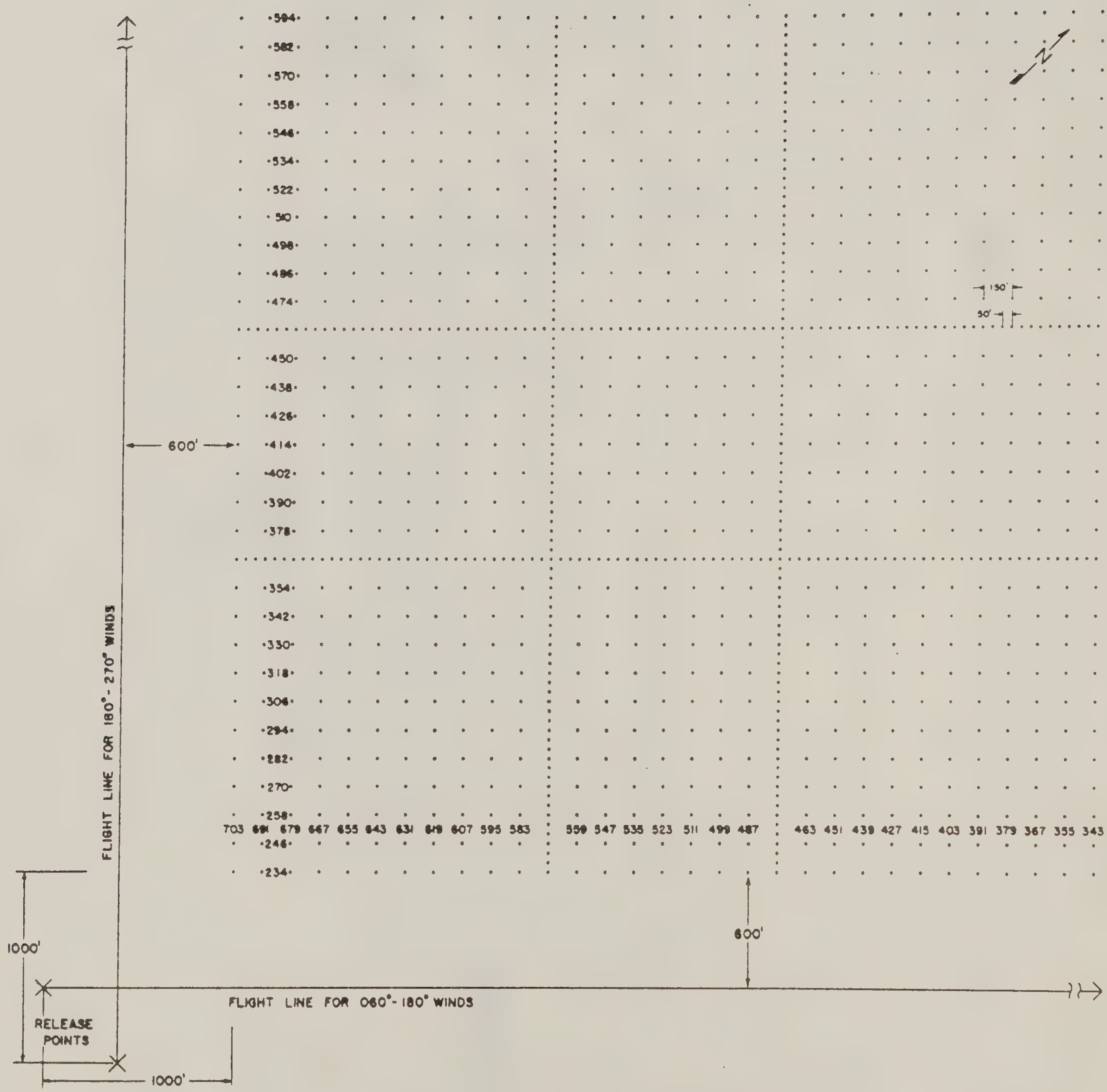


Figure 3 Grid diagram for C 599, Phase C

a. On all trials in Phases A and B, one horizontally positioned, ground level filter-paper sampler and Printflex-card sampler were placed at each of the positions indicated in Figure 2. Additional Printflex-card samplers were placed at 25-foot intervals between positions 59 and 957 on rows 366, 486, and 762. On Phase C trials the same type samplers were placed at each of the positions indicated in Figure 3.

b. The filter-paper samplers consisted of three layers of E and D Number 618 filter-paper with an exposed area of 143.7 square centimeters. Printflex-card samplers were 7 inches long and 6 inches wide. The two samplers were placed side by side on stainless steel holders.

2. Vertical samplers: In Phases A and B only, a vertically positioned, cylindrical filter-paper sampler (size 3.75 by 8 inches) was wrapped around a cylinder, 6.83 centimeters in diameter, and placed at a height of 5 feet above the ground at the positions as indicated in Figure 2.

F. Photographic: Three photo-theodolite positions in Phase A and B trials and two in Phase C trials were used to determine emission altitude, length of emission, emission time, discharge point in relation to the grid, and speed and line of flight of the aircraft. Documentary motion pictures and still photographs were taken of the emission spray lines and other operational subjects. The Printflex-card samplers from all trials were photographed.

G. Meteorological: On Phase A and B trials, one 100-foot mast, two 16-meter masts and one 2-meter instrument were installed on Downwind Grid as indicated in Figure 2. On Phase C trials, one 16-meter and two 2-meter instruments were installed on Target V. Wind direction and speed, temperature gradient, air and ground temperature, relative humidity, and cloud cover were measured with sufficient resolution to provide a representative wind track. A planesonde was obtained on each trial at 100-foot intervals from 100 feet above ground surface to 100 feet above spray release height. Pibal data were used to obtain the mean wind direction and speed from surface to release height.

H. Laboratory:

1. Phases A and B: After the completion of each trial, all filter papers were detached from their holders and returned to the Analytical Laboratory for colorimetric analysis by the trinitrobenzene method. A selection of samplers for analysis was made to assure a one-position fringe of blank analyses around the area of contamination. A control sample from the V-simulant lot number used to fill the spray tanks on each trial was provided by the Munitions Section and utilized for the preparation of standards for the analytical assay of each trial.

2. Phase C: After the completion of each trial, all filter-paper samplers were detached from their holders and sent to the laboratory for colorimetric analysis by the fluoborate method. A 10-milliliter sample of the agent fill was provided by the Munitions Section for purity analysis.

I. Evaluation: All contaminated Printflex-card samplers were microfilmed to provide a permanent record. The original cards from Phase A and B trials and photographic prints of the cards from Phase C trials were then sent to TD&A for a preliminary evaluation of the stain size data.

VI. TEST RESULTS:

A. Munition:

1. Both tanks used on each trial in Phase A and B disseminated the agent fill completely and appeared to function normally. Because the tanks were jettisoned after dissemination on Phase C trials, it is not known what portion of the agent fill was disseminated. For all Phase C calculations, it is assumed that complete dissemination occurred.

2. The flow rates can be determined by using the dissemination times (from photographic data) and the amount of agent disseminated. This method is usually not too accurate because of the difficulty in determining photographically, the point at which the flow ceases. Flow rates may also be based on the slope of the curve obtained from plotting cumulative recovery versus crosswind distance. The flow rates using the latter method are given in Table 1. The flow rates for Phase C trials were not calculated because of the extremely low agent recovery on these trials.

Table 1 The calculated flow rates from C 599 Phase A and B trials

TRIAL NUMBER	FLOW RATE (gal/sec)	AMOUNT OF MATERIAL RECOVERED ON WHICH SLOPE IS BASED (%)
A-1	38.7	100
A-2[a]		
A-3	53.8	85
A-4	44.7	92
B-1	39.4	99
B-2	30.8	98

[a]Because of the extreme distance between the release line and the first contaminated row, the flow rate for Trial A-2 was not calculated.

B. Aircraft Operation and Photographic Data: A summary of the aircraft operation as determined from the photographic data is presented in Table 2. The flight line in relation to the grid for each trial is shown in Appendix B. These data were determined from three phototheodolite positions on Phase A and B trials, two on Trial C-1 and one on Trials C-2 and C-3.

Table 2 Aircraft operation and photographic cinetheodolite data obtained in C 599 (U).

TRIAL NUMBER	DATE OF TEST (1962)	TIME OF TEST (MST)	RELEASE HEIGHT (Feet)		TRUE AIR SPEED (mph)	DISSEMINATION TIME[a] (Sec)	DISSEMINATION LENGTH (Feet)
			Start	End			
A-1	8 Jun	0645	450	470	507	21.6	16,050
A-2	13 Jun	0530	930	925	555	18.0	14,650
A-3	19 Jun	0524	980	1190	540	13.0	10,300
A-4	18 Jul	0623	470	445	518	18.6	14,130
B-1	5 Jul	2003	1,175	1070	447	25.6	16,800
B-2	17 Jul	0608	720	720	419	16.4	10,080
C-1	9 Aug	0924	190	420	510	11.5	8,600
C-2	13 Sep	0848	1,280	1200	530	7.2	5,600
C-3	14 Sep	0739	535	570	550	8.2	6,620

[a]The dissemination times and lengths given in this table as determined photographically include the visible trail-out of agent.

C. Agent and Sampling:

1. Filter-paper samplers:

a. Horizontal samplers: The point-count technique was used in all trials to determine the amount of liquid agent recovered by the horizontal filter-paper samplers. This is the method of ascertaining area coverage by assigning fixed areas to each sampler and assuming that the sample recovered is representative of that area. The area assignment for all positions on Phase C trials was 2,090.25 square meters. The area assignments for Phase A and B trials are found in the following schedule:

ROW	SQUARE METERS
294-534	5,574.00
582-654	16,722.00
726	24,804.30
Bravo	57,133.50
Delta-Hotel	49,051.20

A summary of the liquid agent recovery data is given in Table 3. Complete data are presented in Part I of Appendix A.

Table 3 Liquid agent recovery data for C 599

TRIAL NUMBER	AMOUNT OF AGENT DISSEMINATED (gm)	AMOUNT OF AGENT RECOVERY (gm)	ESTIMATED AGENT RECOVERY[a] (%)
A-1	1,279,587	1,150,875.85	90
A-2	1,300,906	753,052.10	58
A-3	1,069,120	649,095.77	61
A-4	1,197,487	1,063,185.38	89
B-1	1,177,528	661,667.68	56
B-2	1,156,663	801,347.60	69
C-1	1,263,258	111,034.60	11
C-2	1,276,865	47,242.94	4
C-3	1,265,526	256,904.36	24

[a]The recoveries on Phase C trials are corrected for 83 per cent agent purity.

Area coverage, in square meters, for various contamination density levels obtained in each trial is presented in Table 4. Contour diagrams for the various contamination density levels in each trial are presented in Appendix B.

b. Vertical Samplers: The filter-paper data from the vertically positioned samplers used on Phase A and B trials are presented in Appendix A, Part II. These data are given in terms of micrograms of agent per sampler.

2. Printflex-card Samplers:

a. Only a limited number of Printflex-cards were processed for each trial in order to calculate the mean wind speed between the release height and ground level and to determine the droplet size spectra. The procedure followed in calculating the mean wind speed is explained in detail in Appendix A, Paragraph II, B of DPGR 247[1], excepting that on the present trials, the average stain diameter was weighted for contamination density at the position of stain. The results from these calculations are shown in Table 5.

Table 5 General meteorological conditions for C 599

TRIAL NUMBER	2-METER WIND		100-FOOT WIND[a]		2-METER AIR TEMPERATURE (°F)	2-METER RELATIVE HUMIDITY (%)	TEMPERATURE GRADIENT (F°)	CALCULATED MEAN WIND (mph)
	Direction (°)	Speed (mph)	Direction (°)	Speed (mph)			½ to 16 m	
A-1	167	5.5	135	8.3	41.5	47	-4.2	10.7
A-2	144	7.4	147	19.4	58.0	23	+0.7	26.4
A-3	137	2.2	INOP[b]	9.3	52.6	77	+0.9	3.7
A-4	125	10.6	159	22.0	66.3	22	+0.4	17.5
B-1	177	2.3	187	14.5	85.3	9	+3.9[c]	21.5
B-2	168	9.4	165	21.4	63.9	39	+0.6[c]	19.7
C-1	187	12.8	170	18.9	85.8	20	-0.2	-[d]
C-2	095	3.2	110	4.0	66.0	31	-3.6	-
C-3	096	4.5	101	5.4	59.4	26	+3.7	-

[a]Profile mast for Phase C trials was only 16 meters high.

[b]Inoperative.

[c]This reading was between 2.0 and 16.0 meters.

[d]Dash indicates data not calculated.

[1]Technical Report DPGR 247, Comparative Trials Of The Modified And Unmodified Aero 14B Spray Tank, Bis-filled Dugway Proving Ground, Dugway, Utah, April 1960.

b. The procedure followed in determining the droplet size spectra is explained in Appendix A, Paragraph I of DPGR 247 except that the average stain diameter was weighted once for contamination density at the position of the stain, and again for affiliated total row contamination density. The weighting for contamination density of the affiliated row total has the effect of describing the mass-drop diameter spectrum most precisely around the mass median diameter and least accurately in the ranges of the smallest and largest drop sizes. The results obtained are shown in Figures 4 through 9.

c. These analyses were not made for Phase C trials for the following reasons:

(1) A non-representative portion of the agent disseminated hit the grid.

(2) Because of a malfunction of photo equipment, the exact location of the flight line in relation to the grid cannot be determined.

d. The droplet data used for the calculations for Phase A and B trials are presented in Appendix C. Microfilm negatives of all contaminated Printflex-cards are on file at DPG and are available upon request.

D. Swab Samples: The data on the swab samples taken from the aircraft and spray tanks after dissemination are reported in Appendix D. They are reported in terms of micrograms of agent per sampler. The data from the trials not reported are not available and their absence does not mean that the aircraft was not contaminated during dissemination.

E. Meteorological: A summary of the general meteorological conditions existing at or near burst time is presented in Table 5. Meteorological wind tracks are presented in Appendix E. Complete meteorological data are on file at the Meteorology Division, DPG, and are available upon request.

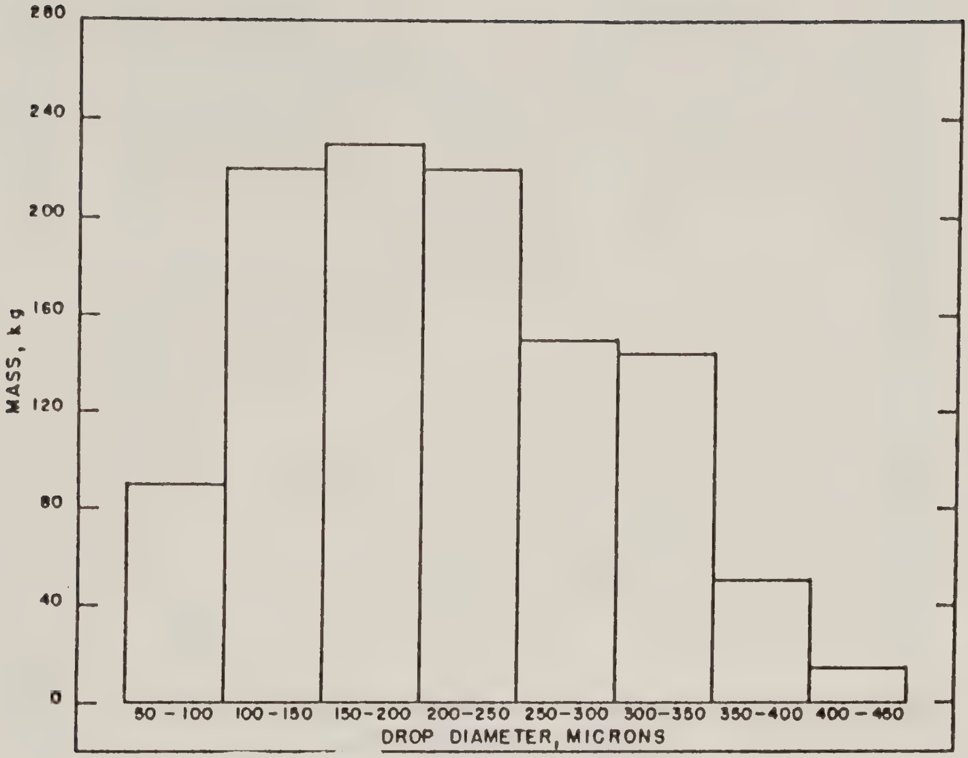


Figure 4 Apparent mass-drop spectra for C 599, Trial A-1

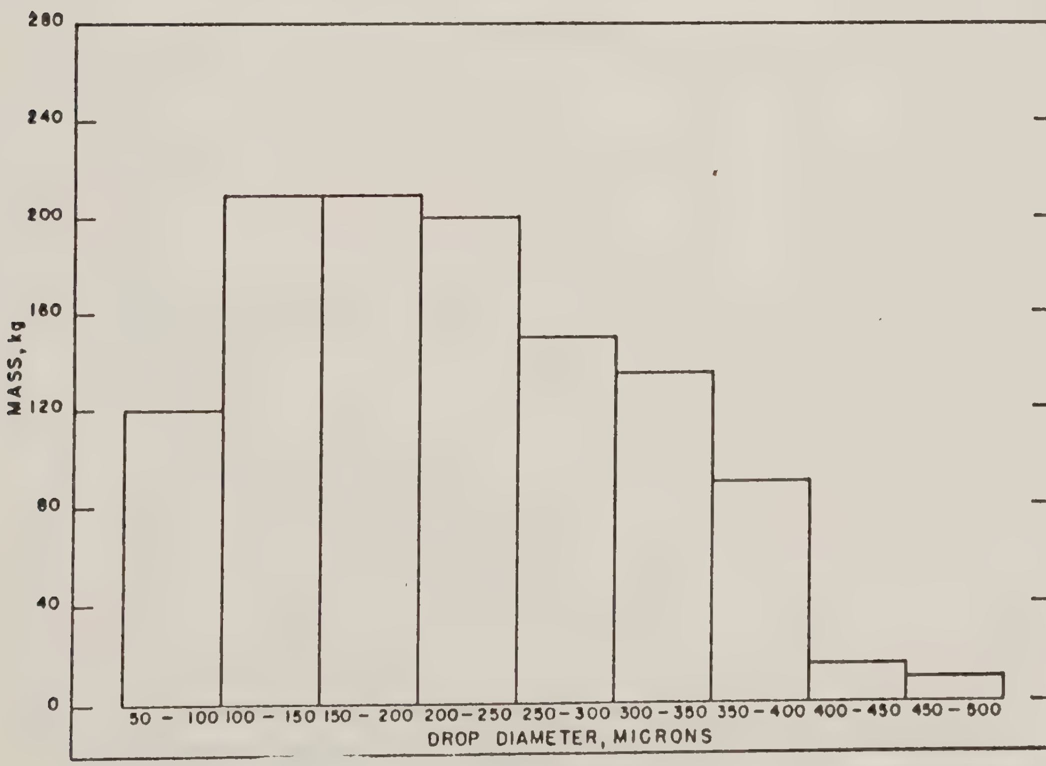


Figure 5 Apparent mass-drop spectra for C 599, Trial A-2

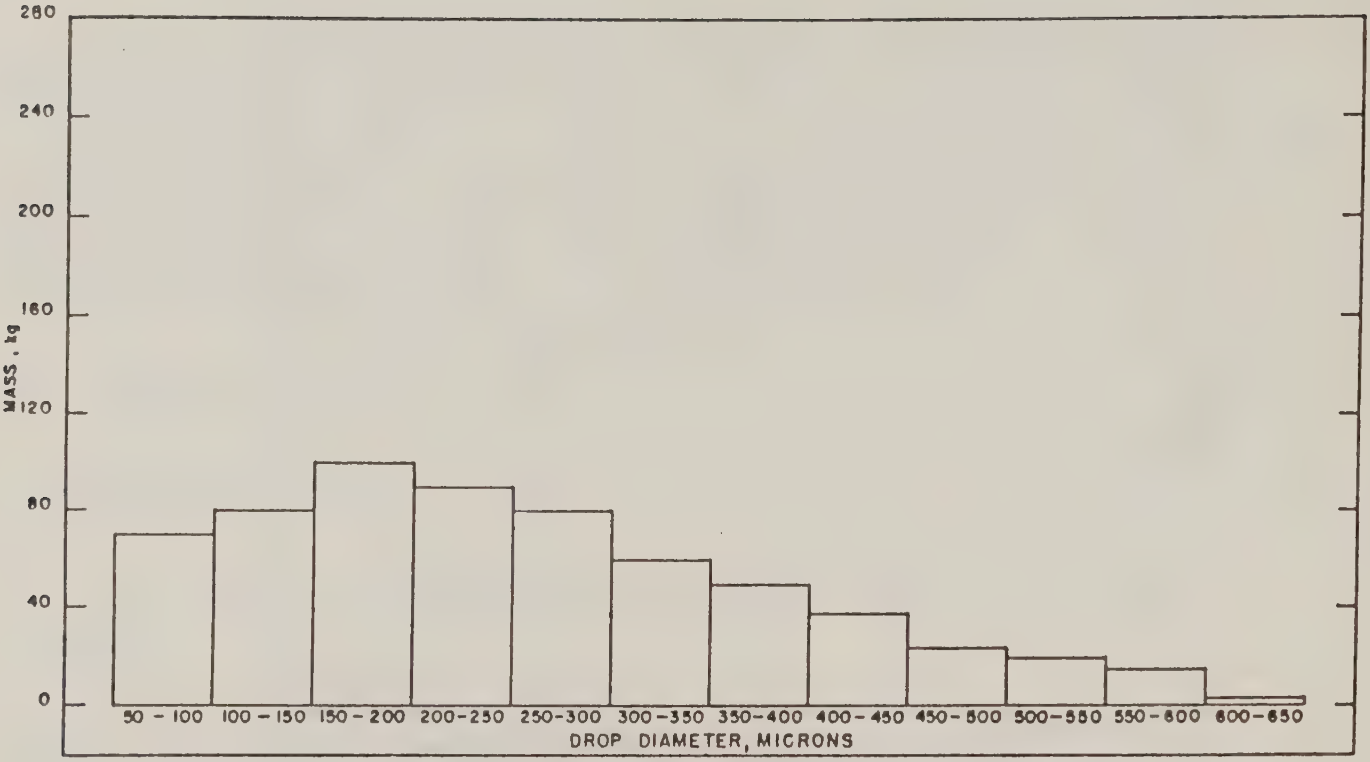


Figure 6 Apparent mass-drop spectra for C 599, Trial A-3

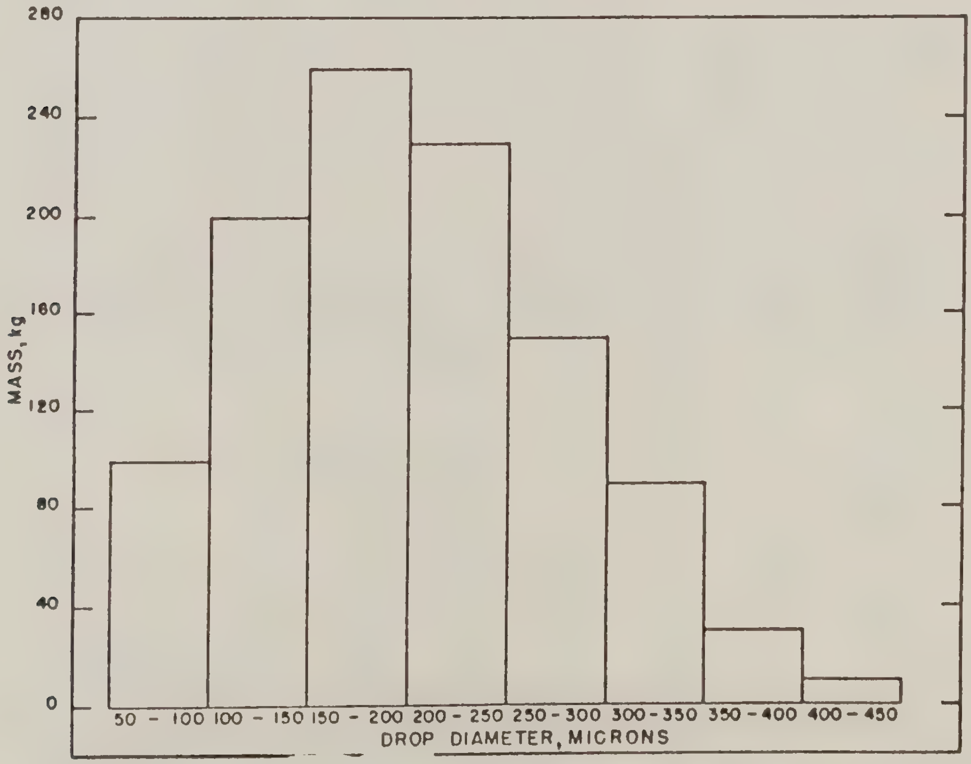


Figure 7 Apparent mass-drop spectra for C 599, Trial A-4

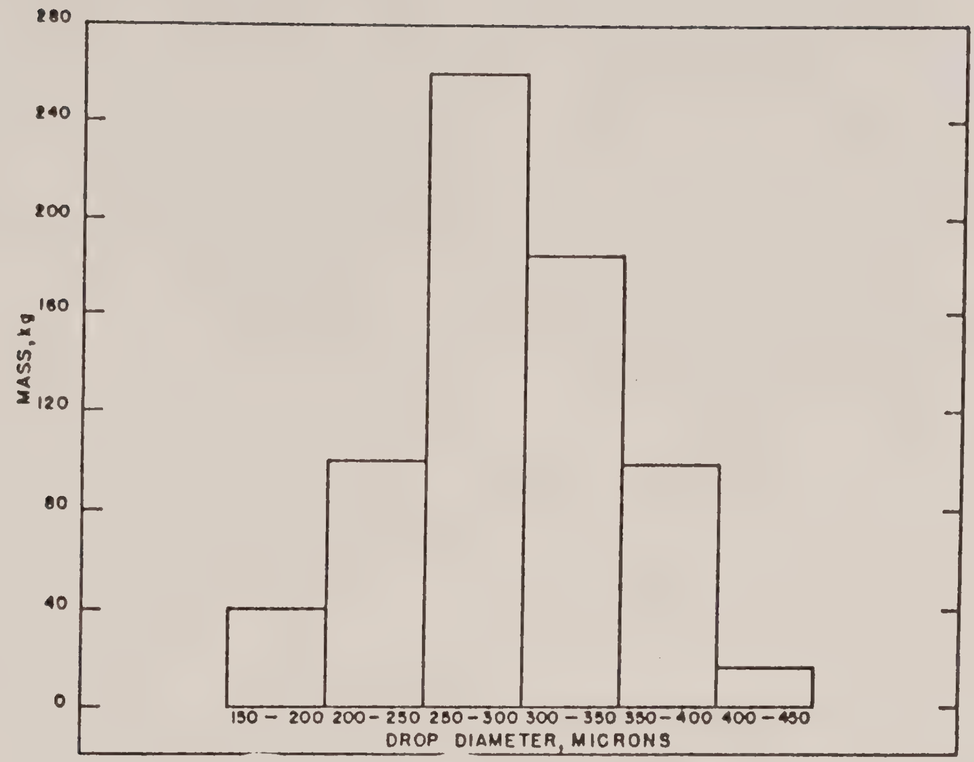


Figure 8 Apparent mass-drop spectra for C 599, Trial B-1

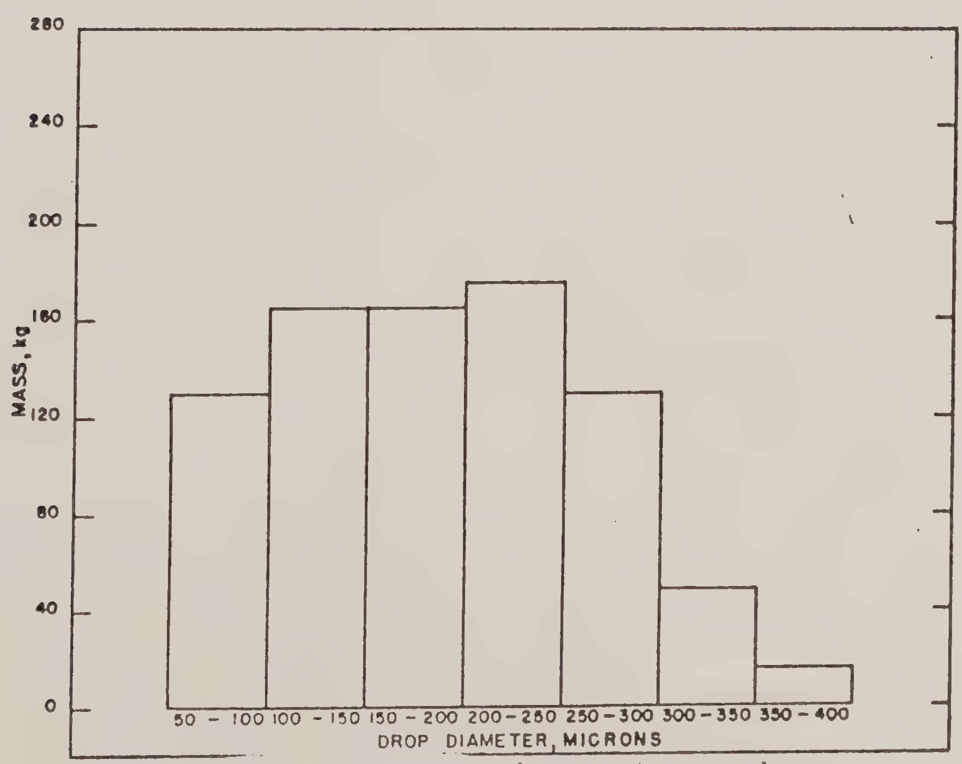


Figure 9 Apparent mass-drop spectra for C 599, Trial B-2

APPENDIX

VI

TRIAL RECORD DPGTR 326
PHASE III CHEMICAL DISSEMINATION
TESTS OF DUMMY FUSELAGE FOR
SD-2 DRONE, DPGTP 582 (U)

Chemical Branch
Test Design and Analysis Division
Technical Plans and Evaluation Directorate
May 1963

U.S. Army
Test and Evaluation Command
Dugway Proving Ground
Dugway, Utah

INTRODUCTION: This series of trials was conducted in accordance with Dugway Proving Ground Test Plan DPGTP 582 (Reference A). Eight of the trials, using V-simulant, were run on Target S, a permanent grid located 15 miles southwest of Dog Area, Dugway Proving Ground (DPG), Utah.

In Phases A, B, and C, (bis 2-ethyl hexyl hydrogen phosphite) was used in each trial. In each trial, a single spray module was attached to a SD-2 drone dummy fuselage and the complete assembly was then mounted on a wing of a B-26 bomber.

V. (U) OBJECTIVES:

A. General:

1. To determine the dissemination capability of the AN/USD-2 Drone Module; and,

2. To investigate possible contamination of the module, fuselage, and/or aircraft used to transport the module.

B. Specific:

1. To measure mass-droplet size spectra and compare spectra from agent and simulant trials (from trials of Phases A, B, and D);

2. To measure the uniformity of flow of agent and simulant from the spray module (from trials of Phases A, B, and D);

3. To measure contamination density and area coverage from horizontally positioned samplers at ground level (from all trials);

4. To measure contamination density on vertically positioned samplers at 5 feet (from trials of Phases A and B only);

5. To measure lateral (90° to the wind direction) diffusion of the droplet clouds during the fall-out (from trials of Phase C only);

6. To obtain liquid agent recovery data from horizontally positioned samplers at ground level (from all trials); and,

7. To obtain release height, point of initial release, and length of release path of the droplet cloud by photographic procedures.

TEST MATERIALS AND PROCEDURES:

Munition:

1. The chemical spray module attached to a SD-2 drone dummy fuselage was used for this series. Each spray module had a flow rate of approximately 5 gallons per second.

2. For each trial the SD-2 drone was mounted on one wing of a B-26 bomber.

3. each module was weighed before and after filling and after release of simulant. The amount of material used as well as the amount of material remaining in the module was reported.

4. Following each trial, the module, dummy fuselage, and aircraft were inspected for evidence of contamination (presence of the red dye used in the agent or simulant). In case evidence of contamination was detected, all surfaces showing such contamination were to be swabbed with material prepared by Analytical Branch. Swabbing was to include all dyed areas and was to be done with the use of a minimum number of swabs. Swabs used on the module, dummy fuselage, and aircraft, were to be grouped, with respect to module, fuselage, and aircraft, identified and returned to Analytical Laboratory for analysis.

Agent:

1. (C) Phases A, B, and C used approximately 24 gallons (200 pounds) of Bis-simulant (bis-ethyl hexyl hydrogen phosphite) per trial. The fill in each module was dyed with 6.0 grams of DuPont Oil Red (C.I. 258) per liter of agent.

2. A control sample from the Bis-simulant lot number used to fill the modules was supplied to the Analytical Laboratory to be used in preparation of standards for the assay of each trial of Phases A, B, and C.

Sampling:

1. Horizontal Samplers: On all trials, except on Trial C-3, one horizontally positioned ground-level Printflex-card sampler (17 by 22 centimeters) and one filter-paper sampler (exposed area 143.71 square centimeters) was placed at each of the positions indicated in Figures 1, 2, and 3. Each filter-paper sampler consisted of three layers of Whatman's Number One filter-paper. On Trial C-3 a final attempt was made to obtain a parallel wind-flight line system and, for economic reasons, only Printflex cards were used at each of the sampling stations.

2. Vertical Samplers: On Phases A and B only, a vertically positioned, cylindrical filter-paper sampler (20.3 by 9.5 centimeters) was placed at a height of 5 feet above the ground at the positions indicated in Figure 1.

Laboratory: Following the completion of each trial, all filter-papers were detached from their holders and sent to the Analytical Laboratory for colorimetric analysis by the trinitrobenzene method for Bis-simulant A first selection of samples for analysis was based on contamination observed on Printflex cards. A second selection was made to assure a one-position fringe of blank analyses around the area of contamination.

Meteorological:

1. Phases A, B, And C: On each trial, four 2-meter anemometer and direction instruments and one 16-meter profile mast were installed on Downwind Grid as indicated in Figures 1 and 2. In addition, one meteorological station was installed immediately upwind of the spray release line to obtain pibal and meteorological observation data.

2. The above instruments were used to record wind direction and speed, temperature gradient, air and ground temperature, relative humidity, and cloud cover. Pibal data were used to obtain the mean wind direction and speed from surface to release height.

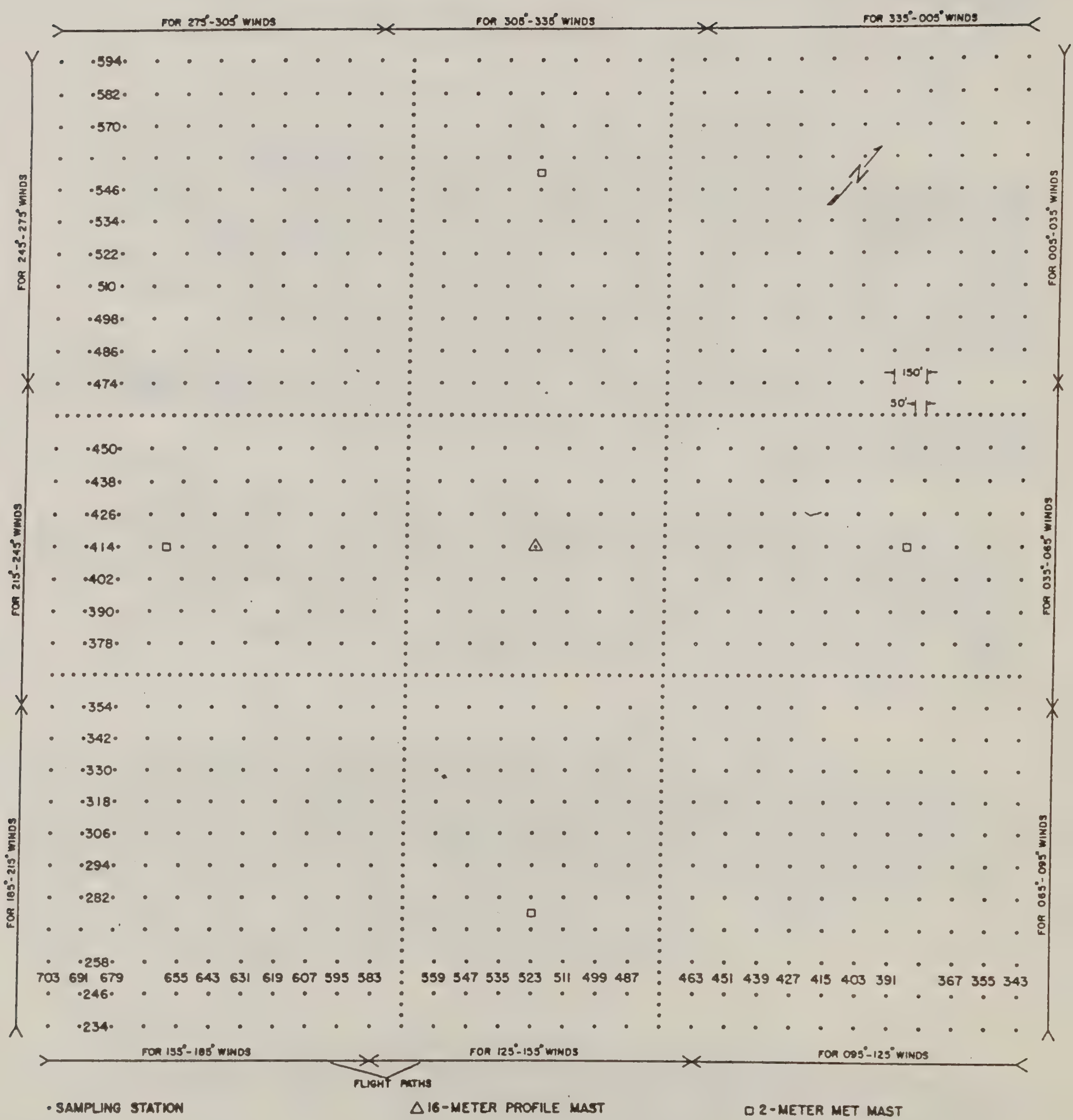
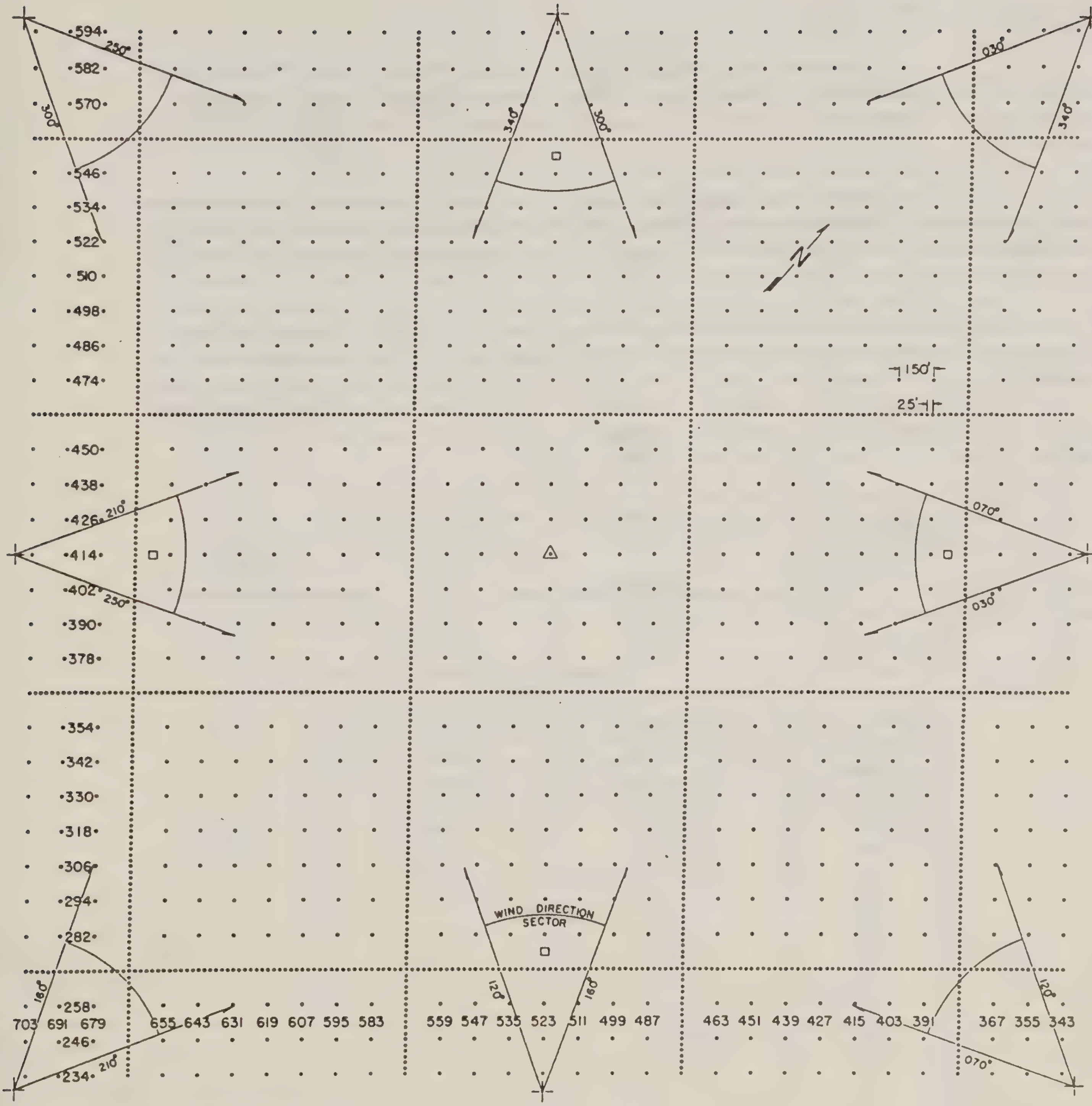


Figure 1 Grid diagram used for C 582, Phases A and B



┼ STARTING POINT FOR DISSEMINATION

• SAMPLING STATION

△ 16-METER PROFILE MAST

□ 2-METER MET MAST

Figure 2 Grid diagram used for C 582, Phase C

F. Photographic:

1. Documentary motion pictures and still photographs were taken of the placement of samplers, plane loading operations, emission spray line, visual effect of spray upon samplers, and of operational subjects.

2. The following data were obtained from three photo-theodolite positions: emission altitude, length of emission, emission time, discharge point in relation to the grid, and speed and line of flight of the aircraft.

3. At the conclusion of each trial, in all phases, all contaminated Printflex cards were microfilmed to provide a permanent record,

In Phases A, B, and C a microfilm camera was set up in the Photographic Building in Dog Area to photograph the contaminated Printflex cards.

RESULTS:

The amount of simulant disseminated on each trial is shown in Table 1.

Table 1 Amount of simulant or agent disseminated in C 582

TRIAL NUMBER	AMOUNT DISSEMINATED IN POUNDS	
	Simulant	Agent
A-1	174.5	-
A-2	177.5	-
A-3	177.0	-
B-1	177.5	-
B-2	179.0	-
C-1	174.0	-
C-2	177.5	-
C-3	178.5	-

Sampling:

1. Filter-paper Samplers:

a. Horizontal Samplers:

(1) The point-count technique was used in all trials to determine the amount of liquid agent recovered by the horizontal filter-paper samplers. This is the method of ascertaining area coverage by assigning fixed areas to each sampler and assuming that the sample recovered is representative of that area. These area assignments are given in Dugway Proving Ground Test Plan DPGTP 582 (see Reference A). A summary of these data is given in Table 2. Complete data are presented in Tables 1 through 10 of Appendix A; contour diagrams for various contaminated density levels obtained in each trial are presented in Figures 1 through 9 of Appendix B.

Table 2 Liquid agent recovery data for C 582

TRIAL NUMBER	AMOUNT OF AGENT DISSEMINATED (gm)	AMOUNT OF AGENT RECOVERY (gm)	ESTIMATED AGENT RECOVERY (%)
A-1	79,151	66,321	83.8
A-2	80,512	63,694	79.1
A-3	80,258	56,151	70.0
B-1	80,512	59,292	73.6
B-2	81,193	49,858	61.4
C-1	78,925	79,305	100.0
C-2	80,258	19,262	23.9
C-3	80,966		-

(2) Area coverages, in square meters, for various contamination density levels obtained in each trial are presented in Table 3.

Table 3 - Area coverage in square meters for C 582

TRIAL NUMBER	CONTAMINATION DENSITY (mg/m²)					
	⩾5	⩾10	⩾50	⩾100	⩾500	⩾1000
A-1	503,769	407,614	190,220	129,600	35,536	-[a]
A-2	1,119,850	869,578	301,008	186,040	2,090	-
A-3	716,982	589,472	263,381	146,323	10,451	2,090
B-1	616,647	520,492	284,285	171,407	14,632	-
B-2	206,943	179,769	112,878	77,342	27,174	14,632
C-1	654,273	487,047	175,588	114,968	37,626	14,632
C-2	165,137	144,234	96,156	64,801	4,181	-
C-3[b]	-	-	-	-	-	-
						-
						-

[a]Dash indicates no area coverage.

[b]Filter-paper samplers were not used in this trial.

b. Vertical Samplers: The data collected by the vertically positioned cylindrical filter-paper samplers at 5 feet above ground level (for Phase A and B only) are presented in Appendix A, Tables 10 through 14. These data are given in terms of micrograms per sampler.

2. Printflex Card Samplers: Only a limited number of Printflex cards were processed for each trial in order to calculate the mean wind speed between release height and ground level. The procedures followed and the results obtained may be found in Section VII, Paragraph C of this report. The stain size data obtained for these trials may be found in Appendix C. Microfilm negatives of the contaminated Printflex cards of this series are on file at DPG, and printed copies are available upon request.

3. Swab Sampling: On Phases A, B, and C no contamination was detected on the module, dummy fuselage, and aircraft, therefore no swab samples were taken.

C. Meteorological Data: A summary of the general meteorological conditions existing at or near release time is given in Table 4; complete meteorological data can be found in Appendix D. For an

Table 4 Summary of meteorological data for C 582

TRIAL NUMBER	DATE	SPRAY RELEASE TIME (MST)	2-METER WIND Direction (°)	2-METER WIND Speed (mph)	16-METER WIND Direction (°)	16-METER WIND Speed (mph)	CALCULATED MEAN WIND[a] (mph)
A-1	12 Dec 61	1710	220	2.0	260	3.4	3.0
A-2	13 Dec 61	1715	315	2.0	338	9.0	8.6
A-3	4 Jan 62	1356	344	10.0	014	13.8	11.7
B-1	10 Jan 62	1330	297	10.0	320	12.4	13.0
B-2	11 Jan 62	1621	358	3.8	018	5.8	3.5
C-1	5 Dec 61	1546	360	1.2	014	1.6	-[b]
C-2	20 Dec 61	1632	159	10.0	168	20.0	-
C-3	5 Feb 62	1710	259	-	310	-	-

[a]On Phase C, the mean wind speed is not calculated because the test did not require this calculation as one of its objectives.

[b]Dash indicates no data recorded or, for calculated wind speed, no calculation possible.

Table 4 (Concluded).

TRIAL NUMBER	MEAN WIND[c] Direction (°)	MEAN WIND[c] Speed (mph)	AIR TEMPERATURE (°F)	TEMPERATURE GRADIENT (F°) 2.0 to 4.0[d]
A-1	221	1.5	20.2	-[b]
A-2	260	5.5	20.5	-
A-3	353	3.1	37.7	3.0
B-1	314	7.6	19.7	3.1
B-2	237	3.1	31.5	1.3
C-1	194	2.2	40.5	2.3
C-2	139	6.3	-	0.0
C-3	153	3.4	39.9	-

[c]Mean wind from surface to release height obtained from pibal data.

[d]According to test design the temperature gradient range desired was 0.5 to 4.0 meters but, because of inoperative equipment, the 2.0 to 4.0 meters was used.

explanation of the method used in calculating the mean wind speed refer to Appendix A, Paragraph II, B of DPGR 247[1]. A modification of this method in DPGR 247 was used in that the average stain size diameter was weighted for contamination density at the position of the stain.

D. Photographic Results: The spray release data obtained on each trial by photographic methods are summarized in Table 5.

Table 5 Summary of photographic data obtained in C 582

TRIAL NUMBER	RELEASE HEIGHT[a] (Feet)	AIRCRAFT SPEED (mph)	LENGTH OF DISSEMINATION[b] (Feet)	DISSEMINATION TIME (Sec)	POSITION OF DISSEMINATION LINE RELATIVE TO FLIGHT LINE[c]
A-1	288	368	3350	6.2	On flight line, 450 feet late;
A-2	315	345	3340	6.6	125 feet left, 100 feet late;
A-3	225	341	3850	7.7	On flight line, 350 feet late;
B-1	323	324	2800	5.9	150 feet left, 225 feet late;
B-2	320	330	3300	6.8	50 feet left, 375 feet late;
C-1	368	349	3840	7.5	On flight line, 25 feet late;
C-2	373	344	2420	4.8	On flight line, 632 feet late;
C-3	420	319	1870	4.0	On flight line, 600 feet early;

[a]Data given for midpoint of dissemination line.
[b]End point includes calculation to point of visible trail-out.
[c]See Appendix B, Figures 1 through 9.

[1]Technical Report DPGR 247,

7, Sten 5

E Flow Rate: From the above dissemination times, and the amounts of material disseminated (Table 2), flow rates may be determined. This determination is usually not too accurate because of the difficulty in determining photographically, the point at which the flow ceases. Flow rates may also be based on the slope of the curve obtained from plotting cumulative recovery versus crosswind distance. Both photographically determined and, where possible, slope-estimated flow rates are presented in Table 6.

Table 6 Photographically determined and slope-estimated flow rates for C 582

TRIAL NUMBER	PHOTOGRAPHIC FLOW RATE (gal/sec)	SLOPE-BASED FLOW RATE (gal/sec)[a]	AMOUNT MATERIAL RECOVERED ON WHICH SLOPE IS BASED (%)
A-1	3.5	5.4	90.0
A-2	3.3	4.7	89.0
A-3	2.9	4.9	97.0
B-1	3.8	5.6	91.0
B-2	3.3	7.5	91.0
C-1	2.9	-[b]	-
C-2	4.6	-	-
C-3	5.5	-	-

[a]On Phase C, the flow rate is not calculated because the test did not require this calculation as one of its objectives.

[b]Dash indicates no data recorded.

F. Flight Results: The flight results pertaining to the portion of the grid used, the flight of the plane, and the release height-wind speed product on each trial are summarized in Table 7.

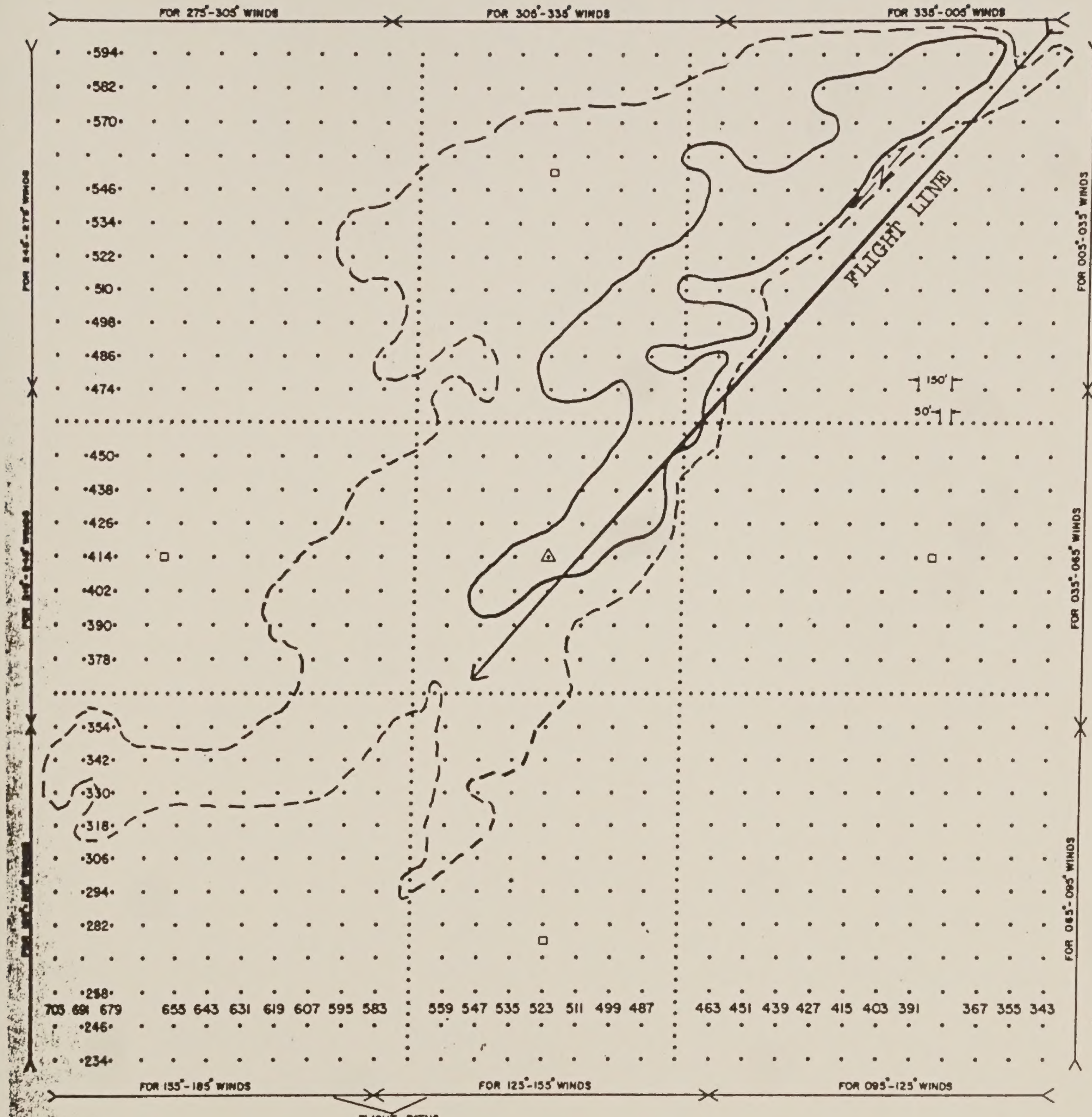
Table 7 Flight data for C 582, Phases A through D

TRIAL NUMBER	GRID SECTOR[a]	AIRCRAFT HEADING (°)	RELEASE HEIGHT-WIND SPEED PRODUCT[b] (ft/mph)
A-1	NW	050	855
A-2	NW	050	2706
A-3	NW	050	2621
B-1	NE	140	4205
B-2	NW	050	1120
C-1	N	180	-[c]
C-2	S	0	-
C-3	-	-	-
			-

[a]See Figures 1, 2, and 3.

[b]Data obtained by multiplying release height by the calculated mean wind speed.

[c]Indicates no data recorded.



• SAMPLING STATION △ 16-METER PROFILE MAST □ 2-METER MET MAST

--- $\geqslant$10 mg/m^2 —— $\geqslant$100 mg/m^2

Figure 6 Contamination density level contours for C 582, Trial C-1

100% recovery